Numerical Investigation on the Performance of Roots Blower Varying Rotor Profile

A Thesis submitted in partial fulfillment of the requirements for the degree of

Master of Technology in Mechanical Engineering

by

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Under the guidance of

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June, 2014

Dedicated to

My Father,

Shri V. N. Verma

National Institute of Technology Rourkela

CERTIFICATE

This is to certify that the research work that has been presented in this thesis entitled "**NUMERICAL INVESTIGATION ON THE PERFORMANCE OF ROOTS BLOWER VARYING ROTOR PROFILE**" by **Satish Kumar Verma (Roll No. 212ME5411)** has been carried out under my supervision in partial fulfillment of the requirements for the degree of Master of Technology in Mechanical Engineering (Cryogenics and Vacuum Technology Specialization) during session 2013-2014 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.

To the best of my knowledge, this dissertation work has not been submitted in any other college or university at any time prior to this, for the award of any degree or diploma.

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DECLARATION

I certify that

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ACKNOWLEDGEMENT

I would like to express my sincere thanks to Dr. Suman Ghosh for his supervision and support in completion of this thesis. The problem discussions with Dr. Suman Ghosh were always been very insightful, and I will always be thankful to him for all the information he shared with me. His prompt responses and availability despite his constantly busy schedule were truly respected. The reality is that Prof. Suman Ghosh was much more than an advisor for me. His encouragement and efforts led this report to successful completion in a timely fashion.

I am very thankful to Prof. Manoj Kumar Mohrana (NIT Rourkela) and Prof. Arup Kumar Das (IIT Kharagpur) for their valuable information on CFD package. I am also thankful to PhD scholar Mr. Tekendra Bhatt and my colleague Pranjal Bhuyan for their continuous help and assistance.

I am also thankful to all the staff and faculty members of Mechanical Engineering Department, National Institute of Technology, Rourkela for their consistent encouragement.

I also thanks to all my friends, without whose support my life might have been miserable here. I wish to express my gratitude to my parents, whose love and encouragement have supported me throughout my education.

Satish Kumar Verma

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

LN_2	Liquid Nitrogen.
LO_x	Liquid Oxygen.
LH_e	Liquid Helium.
i^+	Ion Current.
P	Pressure.
Q	Throughput.
Q/P	Pumping Speed.
S	Pumping Speed.
γ	Angle of Involute Curve from Lower Circle $R_{L.}$
Φ	Angle of the Rotor Curve varies from 0^0 to $\pi/2$.
R_L	Radius of Lower Circle.
α_1	Angle from 0^0 to 40^0 for Circular Arc 1 of Radius R_{ex}.
α_2	Angle from 400 to 700 for Involute Convex Arc.
X_0	Centre Distance of Curve 1 on the X-axis.
Y_0	Radius of Circle Parallel to Circle R_L on Y-axis.
R_{ex}	Radius of External Circle, Curve 1.
X (Φ)	Value of X coordinate for any Angle Φ.
Y (Φ)	Value of Y coordinate for any Angle Φ.
K_{21}	Constant Value for Convex Involute Curve Dependent on Lower Circle Radius.
K_{22}	Constant Value for Convex Involute Curve Dependent on Lower Circle Radius.
R_{up}	Radius of 3^{rd} Curve.
W_R	Width of Rotor.
PDP	Positive Displacement Pump
RPM	Rotation per minute
HV	High Vacuum
VHV	Very High Vacuum
UHV	Ultra High Vacuum
CFD	Computational Fluid Dynamics
Kg/sec	Mass flow rate
Rad/sec	Speed of rotation
K	Temperature in Kelvin

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ABSTRACT

Abstract—Root/Lobe is the most essential part of Roots blower and its design affects the operating performance directly. So, the rotor profile must be improved so that the flow area is maximized while the leakage is minimized and friction due to meshing between the rotor surfaces is made as small as possible. Here an attempt has been made to study the performance of a root blower numerically by varying the shape of the rotor profile. Finite Volume Method (FVM) has been adopted here to perform the hydrodynamic calculations. Four different profiles have been considered by varying the west width of the rotor. Pressure contour, Temperature contour, velocity contour, velocity vector mass flow rate etc. have extracted for each of these rotor profile and have been compared.

Keywords: Roots blower, Computational fluid dynamics, Compressible flow, Optimization.

CHAPTER 1: Introduction and Literature Review

In this chapter, Introduction, Literature Survey, Gaps in the Literature, Aims and Objective of the current work have been described.

1.1 INTRODUCTION

A Pump is a mechanical device which is used to transport fluids (it can be in gaseous form or in liquid form) from one section to another in various industrial processing plants. The operation of a pump is performed by reciprocating or rotary action using some electrical or mechanical energy such as electrical motor, manual operation, diesel or petrol engines or wind energy. Pumps have a large number of applications in industrial uses as well as in our daily life. These are used for pumping ground water, in aeration, pumping natural gas and oil from well, used in various cooling towers, transportation of cryogenic fluids like LN_2, LOx, LHe, etc.

In a given space if the air density is less than 2.5×10^{19} molecules per cm^3, it is said to be 'vacuum' and the technology used to create the same is called 'vacuum technology'. Gaseous molecules due to convection interact with the surrounding and destroy the desired process conditions. To overcome the above mentioned problem, vacuum plays a vital role to maintain thermal isolation. We create vacuum so that heat energy loss due to convection and conduction can be greatly minimized. Losses due to conduction and convection are the major issue associated with cryostat and certain vessels containing cryogenic fluids. To create vacuum, now a day's vacuum pumps with different pumping techniques are used. For the large volumetric efficiency and due to simple construction, roots blowers are widely used.

Roots Blower is positive displacement type pump used in several industrial processes and is most effective in moderate compression ratios. Generally roots blower works in the compression range of 1.1 to 1.2. They are used for constant flow rate at varying discharge pressures. Roots blower consists of 2-lobes in which one is a driving lobe which is driven by the external driving source connected directly to the lobe shaft while the second lobe is driven by rotation of first lobe. Hence in the process both lobes rotate at the equal speed and in the opposite direction, one in clockwise while the other is in counter-clockwise. As the rotor rotates, fluid is drawn inside at the inlet of the blower and forced out against system pressure.

Roots blowers mainly consist of five parts namely, rotors, chamber, inlet, outlet and shell. In one working period, the rotor rotates in forward-reverse direction respectively. The fluid is compressed and transported from the inlet to the outlet through the chamber (shell). In the rotation cycle neither rotors make contact with the inside surface of the shell or with each other and hence no frictional forces exist between the moving parts. This special non-contact technique provides higher performance and greater fluid flow than a conventional pump. The flow discharge through the chamber depends on the operating speed of prime-mover. The pressure across the blower is also a deciding factor for the input power applied for the rotation of the blower. The suction and discharge pressure are determined by the system conditions. The rise of in the discharge temperature is largely dependent on the differential pressure across it. The most of the supplied energy is utilized to heat the flow (liquid/gas).

1.1.1 VACUUM PUMP OPERATION RANGE

In vacuum technology, the devices used to generate vacuum have certain limitation on their working range. It is not possible to obtain the desired vacuum level with a single or with a particular device at high level i.e. no vacuum generating device can cover the pressure range from 760 Torr to 10^{-13} Torr alone. So, depending on the final pressure required in the vacuum operation, combinations of different types of vacuum pumps have to be used. The chart below gives the range of pressure that can be obtained by different pumping methods.

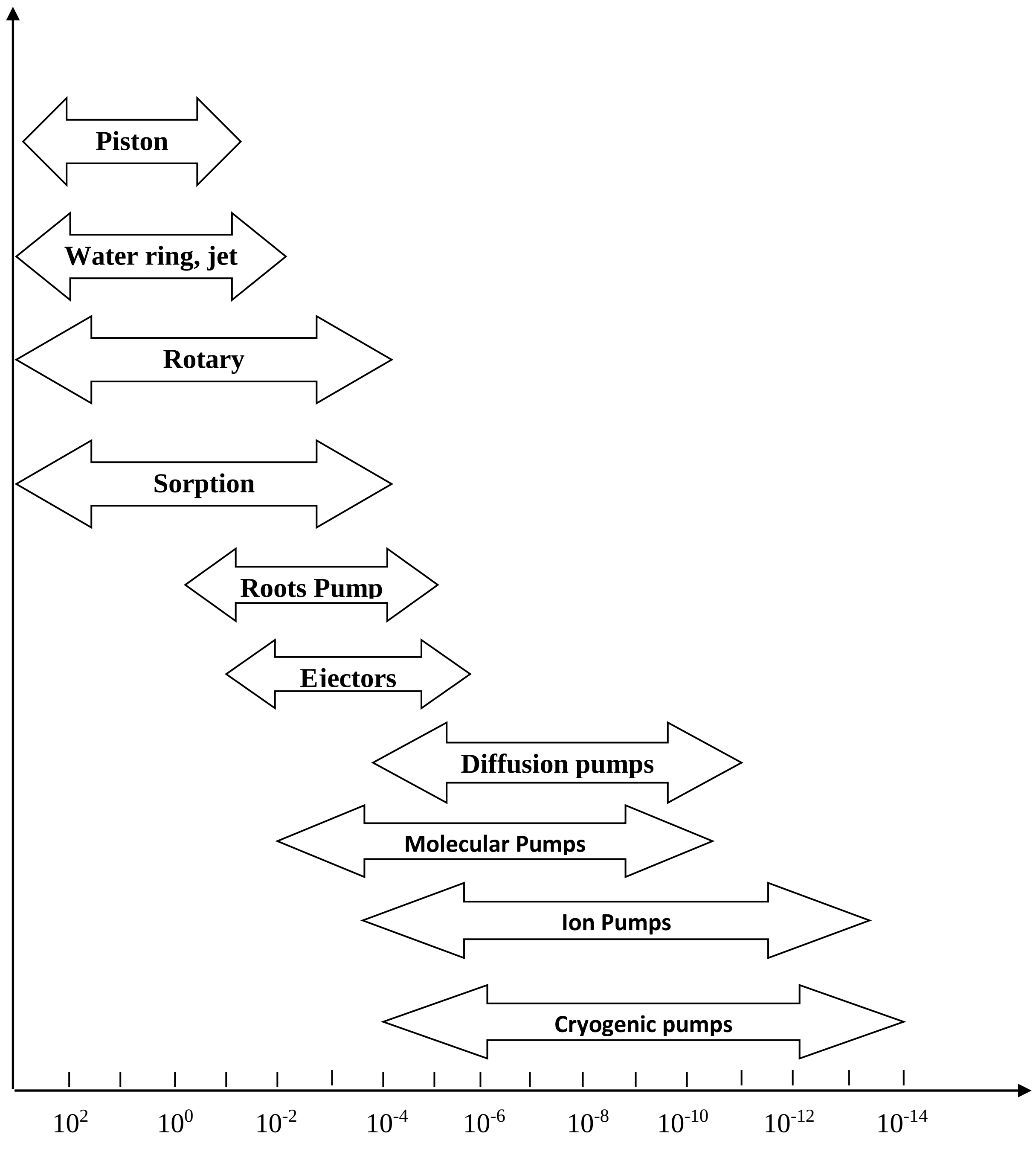

Figure 1.1: Vacuum Pump Operating Range.

1.1.2 CLASSIFICATION OF VACUUM PUMPS

Vacuum pumps can be classified mainly into two parts based on their evacuation process and they are Gas Transfer Vacuum Pumps and Gas-Binding Vacuum Pumps.

1.1.2.1Gas Transfer Vacuum Pumps: Gas transfer Pumps evacuate chamber by removing the gas continuously from the chamber and throwing the gas into atmosphere. These pumps are external devices and attached to the vacuum chamber from outside. They need a power source to drive the shaft of the rotors of these pumps. It can be an electric motor driven or diesel engine powered. They are further classified into two parts:

1.1.2.1.1 Positive displacement vacuum pumps: In this type, gas is displaced by changing the volume of the vacuum chamber at a regular interval and is discharged directly to atmospheric pressure. Roots blower pumps and single stage and double stage rotary oil-sealed pumps comes under this category. Examples are Rotary type displacement pumps, Reciprocating type positive displacement pumps and Linear type displacement pumps.

1.1.2.1.2 Kinetic Vacuum Pumps (Momentum transfer): In Momentum Transfer pump, gas particles are accelerated from vacuum chamber to the outlet side (exhaust) with very high speed rotating machine. This type of pumps can operate only after attaining a certain level of evacuation in the desired chamber. This initial level of evacuation is called roughening and is done by positive displacement pump. Examples are mechanical kinetic pumps, propellant pumps and ion transfer pumps.

1.1.2.2 Gas binding vacuum Pumps (Entrapment type): In Entrapment pumps, gas particles are captured on a substance called absorbent. These are internally installed devices and it requires replacement of the absorbent material time to time however we can keep absorbent material inside the chamber keeping the temperature of the chamber very low at the cryogenic level i.e. below 123K. Such as in cryo-pump at very low temperature gases can be condensed on absorbent like zeolite, charcoal etc and can be kept inside.

Based on the above information, a block diagram presentation of main group and sub-groups have been made followed by detailed description of the vacuum pumps:

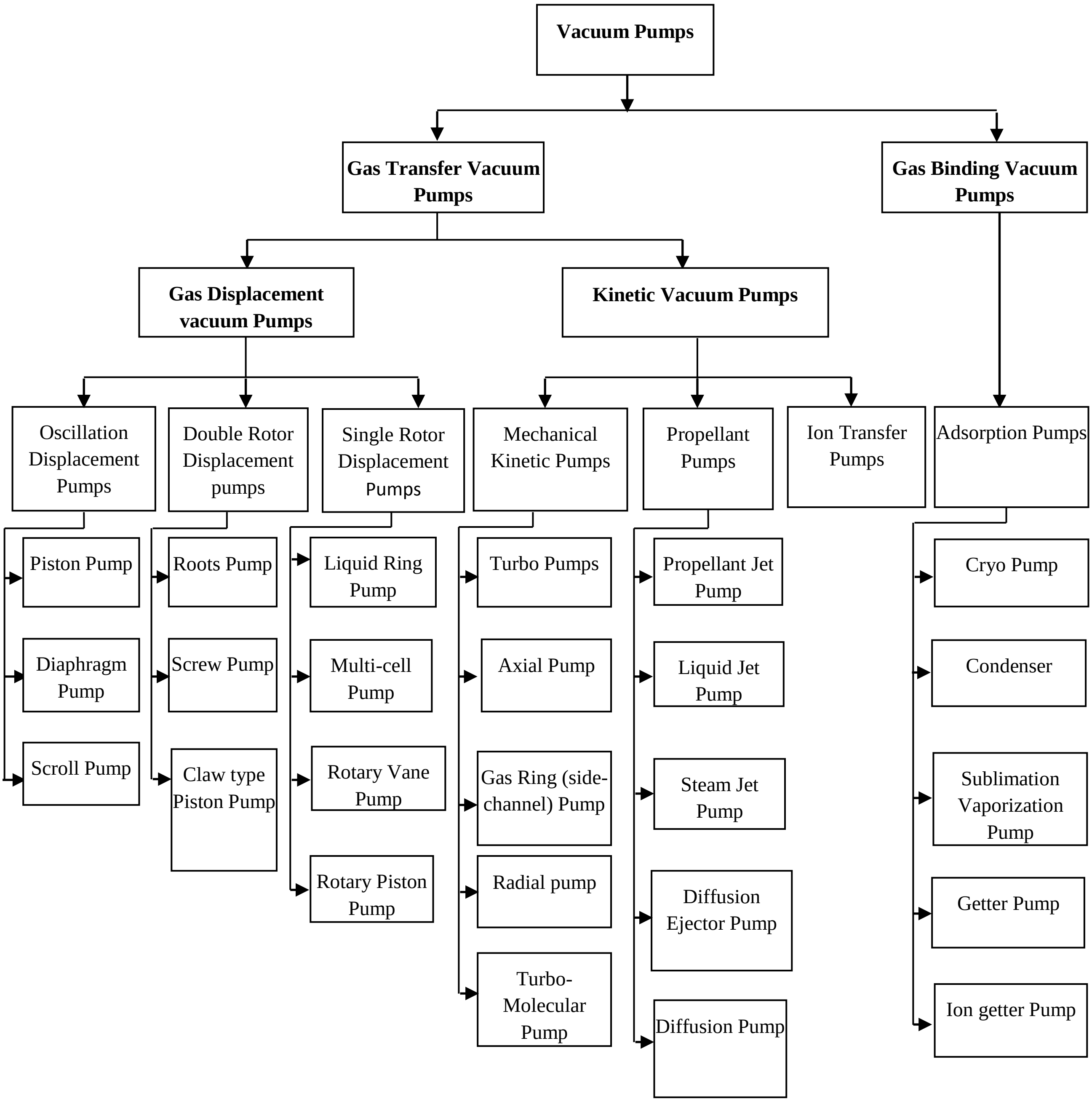

Figure 1.2: Classification of Vacuum Pumps.

1.1.2.3 Piston Pump: It is a PDP type pump which uses cylinder-piton system to exhaust gases from chamber to atmosphere. High pressure rings are used to seal the gaps between the cylinder and piston. It finds application in gas transfer, as superchargers and also for liquid transfer. Its operation is huge as supercharger but can be used ad roughening pump for vacuum generation system. Its range of vacuum generation is of the order of 10^{-02} Torr. Piston pumps are of two types Axial and radial type**.**

- **Axial piston pump:** An odd numbers of cylinder piston systems are incorporated in axial piston pumps, and arranged in a circular array. A common shaft is used to rotate all the cylinders about its axis.
- **Radial piston pumps:** It is a type of hydraulic pump. Pistons are attached to the inner ring in a radial direction eccentrically. And rotated by a shaft attached with the prime mover.

Advantages:

- Their efficiency is high,
- Produces less noise,
- Highly reliable system

1.1.2.4 Diaphragm Pump: It is a positive displacement type pump in which pumping action is executed by reciprocating action of diaphragm. The diaphragm can be a membrane made of rubber, Teflon (PTFE) or thermoplastic. There also exists a valve on one side or on both side of the diaphragm. Butterfly, shut-off, flap valve or check valve can be used.

Working of the diaphragm pump is based on the function that if diaphragm moves up the pump volume increases, pressure decrease inside the pump and fluid get inside; in the next step as the diaphragm moves down, pressure decreases inside and fluid is forced out of the pump which was within the pump volume. The both action completes a cycle of the pump.

Advantages:

- It is low flow rate as well as high flow rate pump, can be used multipurpose.
- It can be used for slurries and sludge transportation with large amount of solid and pulp contamination i.e. fluid with high viscosity.
- Can be used in making artificial hearts, air filters for aquarium.

- It is used extensively in household equipments, pharmaceuticals, chemical plants and several other industrial processes.

1.1.2.5 Scroll pump: Scroll pump has a spiral type design so also known as spiral pump. It consists of two scrolls; the scroll can be of involutes geometry, spiral type, or a combination of curves. Off the two scrolls one is kept fixed and other is made to rotate eccentrically.

It founds applications in vacuum systems, air conditioners and supercharges.

A scroll pump working in opposite direction is called ascroll pump, it may be used for generating mechanical work by expanding the fluids or compressed gas.

1.1.2.6 Screw pumps: In these pumps rotors are helical and moves like screw. Prime mover is attached with screw rotor. It may be of single or double screw rotor type. Rotor is made of metals or some composite material generally it is made of stainless steel so that no rusting and tear-wear occur and reliability would high. When operating, gas is trapped inside the screw and as it rotates the trapped gas molecule moves further, in the series there are many grooves of screw and hence gas get compressed and from the exit point it is taken out.

1.1.2.7 Twin Screw pump: It is having two helical male and female rotors which are meshed with each other in the sense that if one is moving then other will also move. Direct diesel/petrol engine or an electrical motor is attached to rotate the screw rotor. It is further classified into two types, oil free and oil injected pump. Oil free type is used foe low vacuum while oil injected is used for medium vacuum.

1.1.2.7.1 Oil free pump: in this the pumping of gases is completely isolated from oil contamination hence appropriate for pumping variety of gases like particle mixed, explosive gases, and polymerizes.

1.1.2.7.2 Oil injected pump: In this types of screw pump, oil is being injected into the pumped system to cool the medium hence obtaining higher compression ratio and less amount of energy loss and less tear wear of equipment.

1.1.2.8 Claw type Piston Pump: Claw type vacuum pumps are used for roughening purpose in high vacuum system. It can be used for high and medium range vacuum. Friction–less drawing and lubrication free operation makes it highly reliable, contamination free and highly energy efficient device. It is frequently used in industries like power plants, chemical plants, food processing, medical, oil and gas, agriculture and in research work.

1.1.2.9 Liquid Ring Pump: In this pump gas traverses the internal port. The gas is drawn into the rotor chambers by the receding liquid ring, similar to the suction of a piston in a cylinder. In this the liquid ring does the job of pistons, while the rotor chambers play the part of cylinders. As each chamber, in turn, rotates past the inlet port, the chamber carries a volume of air or gas around with it. The gas molecules are confined between the cone and the ring of rotating liquid. The gas is compressed as the liquid ring converse with cone. When each chamber, in turn, rotates to the discharge port opening, the compressed gas escapes from that chamber through the discharge port to the internal discharge passage.

1.1.2.10 Multi-Cell Pump: A single rotor pumps having more than two chambers in the shell. Gas entered from suction side gets compressed multiple times before exit from exhaust**.**

1.1.2.11 Rotary Vane Pump: It is extensively used positive displacement rotary pump. There are stator and cylindrical rotor; rotor is eccentrically housed in the stator at the upper wall surface. Inlet and exhaust port are also there in the stator for in-out of the gas. Inlet consists of a filter which cleans the incoming gas; exhaust has a baffle valve to control the exit point. In the cycle as the rotor is rotated gas is taken inside through the inlet port and compressed further it thrown out via exhaust to the atmosphere.

Advantages:

- Its design is easy; speed of rotation is not very high hence less damage of the parts in operation.
- Its rotor can be joined directly with prime mover hence maximum power transfer to pump.
- Its discharge rate is continuous.
- Since there are less number of parts in moving state, only rotor and vane hence vibration is very less; no foundation formation is required.
- Used largely for roughening vacuum in association with high vacuum devices such as Turbo molecular pump, ion pump, diffusion pump, cryogenic pumps etc.

Disadvantages:

- There is some frictional loss due to contact with stator and rotor at the top.
- Oil lubrication is needed hence oil contamination is a problem.
- It cannot be used for high vacuum.
- Its vacuum generation level is low up to 10^{-04} Torr

1.1.2.12 Rotary Piston Pump: Again a single rotor pump. Having a cylinder piston arrangement attached with a crank which is directly connected to the prime mover. As the crank rotates it rotates the piston and hence the cycle complete and gas compression takes place.

1.1.2.13 Turbo Pumps: This type of pump is driven by very high speed prime movers. After the ejection from the chamber gas molecules are given additional speed in a certain specific direction. Turbo-molecular pumps are example of this type with speed range of 20,000 RPM to 90,000 RPM etc

1.1.2.14 Turbo molecular pump: It is a momentum transfer type vacuum pump. When gas molecules hit the wall, it has an additional velocity component in the direction of the moving wall along with its own thermal velocity component. The particle acquire the resultant velocity of the above two velocity and hence the molecule blown away in the direction of moving wall. Since the gas molecule moves in random motion within the chamber and collide with each other, they get a certain direction in the process. It is occurred only when the wall is moving in a very high speed. The mean free path of the gas molecules is more compared with the distance between the two walls hence the chances of collision between the gas particles is very less while collision between wall is more frequent. Here we can say that effect of the rotating wall is more in the direction of gas particle flow. In these days this type of pump is extensively used in industrial process and vacuum technology. For the operation of turbo molecular pump we need roughening of the chamber which is done by the positive displacement pumps. As the number of stages increases the ratio of gas compression of Turbo molecular pump gets multiplied. Since Turbo molecular pumps have some bearing arrangement for its smooth operation and to reduce frictional hazards there is oil or some grease material is needed. Due to use of oil and/or grease there is possibility of contamination of gas molecules with oil/grease vapors. However it can be reduced by using magnetic levitation of the rotor.

Advantages:

- It can produce ultra high vacuum level of 10^{-14} Torr.
- It is used in the semiconductor device manufacturing units, thin film deposition industry.
- It has very high pumping speed of about 10,000L/sec.
- We can make it operational in a few minute.
- There is no requirement of vacuum valve, can be directly connected.

Disadvantages:

- It may have some oil/grease vapor contamination and decomposition due to ball-bearing arrangement but it can be removed by using magnetic levitation method for the rotation of rotor.
- Since it runs at very high speed, extra care in needed

1.1.2.15 Diffusion Ejector Pump: Ejectors vacuum pumps: In Ejector type, gaseous molecules after pumped out of the chamber are mixed with some working medium and then after mixing moved out with the medium. The Diffusion pump is an example of this type of pump.

1.1.2.16 Diffusion Pump: works on that, the gaseous molecules that are pumped out penetrate the jet of vapor in the way that one gas is being diffuse to another. It uses vapor jet of very high speed to direct gas particle in the throat of pump down to the bottom and from there with secondary roughening pump it is taken out (exhausted out). In the assembly of the diffusion pump there are two pumps in the series one is called roughening pump that is rotary positive displacement pump and anther is diffusion pump. Diffusion pump cannot be operated alone; first with rotary pump a vacuum level of around 10^{-04} Torr is generated. Diffusion pump cannot discharge directly into atmosphere; it is done by roughening pump. Diffusion pump is classified as momentum transfer pump.

IT IS CLASSIFIED INTO 3 TYPES:

1.1.2.16.1 Oil diffusion pumps: It is operated using low vapor pressure oil. It can achieve higher vacuum level as compared to positive displacement pump. Its vacuum range of operation is 10^{-5} to 10^{-10} mbar. Its pumping efficiency is greater when compared Turbo molecular or Cryo pumps in terms of production cost. It's a low cost with high pumping machine.

1.1.2.16.2 Steam ejectors: This is also a very good type of diffusion pump mainly used for vacuum distillation and freeze-drying. Vapor containing jets can be removed from the vacuum chamber. It can be of single stage or can of multiple stages. There it is also optional to use a condenser between the two successive stages.

1.1.2.16.3 Compressed air ejectors: It is a multistage type device using air as the driver. There are suction cups and vacuum lines.

Advantages:

- Low cost, low maintenance device
- High vacuum level generation
- There are no movable parts hence highly reliable and durable

Disadvantages:

- It has chances to get back the oil into the vacuum chamber
- Chances of contamination of the inner walls of the working chamber
- It is not suitable for ultra high vacuum generation
- Cannot be expose directly into atmosphere after use because oil get burnt

1.1.2.17 Cryo Pump: Cryogenic vacuum pumps: This procedure of creating vacuum involves cooling of gas at very low temperature say below 123K, converting into liquid and then into solid. Cryogenic engineering is being used to do such activity in vacuum generation in laboratory as well as in industry. In this system solid gas can be removed from the chamber or can be retained. Now a day, inspite of cooling the whole chamber, a cold body is introduced in the chamber. Gas molecules when strikes on cold body they get condensed. Sometimes porous solid body of special types is used to make availability of large surface area so that a large amount of gaseous molecules can be condensed/ trapped on it. The pumping speed of the solid body surface is

$$S_0 = (V/4) * 10^{-3} \text{ liter/cm}^2\text{.sec}$$

V is average velocity of the gas molecules flowing in the chamber in cm/sec.

It is formulated as: $(8k_BT/\pi M)^{1/2}$ **cm/sec**

Cryo-pumping is not a positive displacement type pump, in it unwanted solid gas can be removed or can be stayed there i.e. the gas molecules are deposited on the surface as a film and is not exhausted out.

Further it can be classified into three main groups based on the method of cooling of the chamber:

- Refrigerator cooled Cryo-pump: Cryo surface is kept inside the vacuum chamber and is maintained at 20K temperature
- Liquid pool Cryo-pump
- Continuous flow Cryo-pump

1.1.2.18 Adsorption pumps: These pumps are used for roughening purpose in Ultra high vacuum systems by pumped down to a pressure range of 10^{-4} Torr or lower. A solid surface is there so that gas molecules can attach to it or can penetrate into solid. If gas particle being deposited on the surface of the solid then this phenomenon is called adsorption and if gas molecule penetrate into solid then it is called absorption. The forces attracting the gas molecule may be physical (Physiosorption) or chemical (chemiosorption). Here in the process solid material is called adsorbent and the gases being removed are adsorbate.

The pumping efficiency of a sorption pump greatly depends on the environment where it is used, the temperature of the absorbent, its adsorption coefficient for particular gas an on the starting pressure of the chamber. Usually temperature is kept low with the surrounding of LN_2 at 77**K**.

By using this in Ultra high vacuum system one can get rid of from the system contamination due to oil of mechanical pumps.

Example of Sorbents used in Vacuum Technology:

In the Cryogenic system for evacuation purpose, mainly three sorbents are used namely Activated Alumina, Molecular Sieves (Zeolites) and Activated Charcoal.

Activated Alumina can be used for both water vapor and oil vapor trapping at room temperature. It has very long life of before saturation. The surface area is around $210m^2/g$.

Molecular sieves or Zeolites: They are Hydrated Alumino-Silicates containing potassium, barium, calcium and sodium. Several sieves found naturally but it can be manufactured synthetically in lab also. In Cryogenics and vacuum system they have extensive use. These materials are out gassed at very high temperature of 350^0**C**. At this temperature, material gets dehydrated leaving voids behind, and lattice of the crystal does not collapse. Hence there are tiny holes in the place of water molecules. While doing evacuation these voids fill with adsorbate.

Examples of sieves are **Linde sieves 4A, 5A and 13X**. General formula for these sieves are $\mathbf{Me_{12}[(AlO_2O)_{12}(SiO_2)_{12}]27H_2O}$ where Me is a metal ion, Sodium in the case of Linde sieve 4A, 4Na+ and 8Ca+ ions for Linde sieve 5A.

Activated Charcoal: Activated charcoal is most widely used, cost effective and easy to construct sorbents. It is constructed by heat treatment of coconut shell and then baking it in vacuum to remove the trapped gases into the cell voids. The resulting material has large surface area of about $2.3*10^{-3}m^2/g$. It can also be used at the room temperature but its adsorbing capacity can be increased extensively by lowering the surrounding temperature. Generally it is done by using liquid Nitrogen (LN_2) at 77K.

1.1.2.19 Ion Getter Pump: Ion pump is based on the principle that ionized charge particles are get attracted on a high voltage electrode of opposite charge say 3,000V to 7,000V in an electric field. An electrical discharge is bombarded with high energy electrons, this e^- ionizes them. Further there are high voltage cathodes that attract the ions and deposit them on the cathode material. This cathode material is chemically active and acts like getter which make vacuum by removing gas particle by chemisorptions or by Physiosorption.

Ion pumps are used to generate vacuum in ultra high vacuum range of 10^{-11}mbar. They are also used jointly with roughening pumps to generate initial vacuum of 10^{-04}mbar.

Pumping efficiency is defined as:

$$(i^+/P) = (KQ/P)$$

Where; i^+= ion current

P = pressure inside the vacuum chamber

Q = throughput

$$Q/P = \text{is pumping speed}$$

Hence pumping speed can be written a:

$$S = 1/K\,(i+/P) = \beta\,(i+/P)\ \text{liter/sec}$$

$$\beta \text{ is } 1/K \text{ called pump constant}$$

Types of ion pumping:

There are mainly two types of ion vacuum pumps. Gas molecules can be ionized by two methods first by bombardment of high energy electron on gas molecules produced by hot filament known as hot cathode ionization and second by cold cathode discharge. The first one is known as hot cathode ion pump while second is known as cold cathode ion pump. Its pumping efficiency can be increased by combining phenomenon of sorption and gettering with ionization. Further they are named as sorption ion pump and getter ion pump.

1.1.2.19.1 Evapor ion pumps: It combines the effect of gettering process of evaporated active metal with ion pumping. Here getter action is performed in both senses as in evaporation and in the form of a new film on the metal surface. Generally before activation of these pumps chamber is first evacuated by diffusion pump at the level below 10^{-03} Torr.

1.1.2.19.2 Sputter ion pumps: in this pump basically there are two electrodes cathode and anode, magnetic field is also provided with a magnet. Anode and Cathode are made of stainless steel and titanium metal respectively. Cathode is attached rounded across the anode and acts as getter plate. Due to presence of high electric and magnetic field electron deflected in a helical direction and hence more chances of collision between the gaseous molecule and generate more ions. It can generate vacuum in the 10^{-12} Torr range.

1.1.2.20 Sorption vacuum pumps: Here the gas molecules are absorbed on an absorbing material by physi-sorption or chemi-sorption. Materials like activated charcoal, titanium surface, molecular sieves and some other getter substance. These getter materials need replacement after certain time period.

1.1.2.21 Roots Blower Pump: It is positive displacement lobe pump which pumps the fluid/gas with a pair of lobed impellers having a structure like 8. As the shaft rotates, gas enclosed in the vacant region is transported from inlet port to the outlet exhaust port. It has no valve at the outlet port. In this two lobes run in opposite direction one in clockwise while another is in counter clockwise. They both are isolated from each other and also isolated from casing i.e. there is no contact among the three parts of the pump lobe, casing and lobe. Since there is no contact type arrangement hence frictional losses due to mechanical parts is minimum. There is clearance between lobe-lobe and lobe-casing is of the range of 0.010 inches to 0.015 inches. To rotate the lobe/rotor of the blower pump, shaft of the lobe is directly connected to the prime mover so that power transfer should maximum. Shaft is connected with only one lobe, second lobe is driven by rotation of first lobe and hence both are synchronized. The speed of rotation of Roots Blower Pump is generally range from 500 to3000RPM.

Its pumping speed depends on various parameters like speed of rotation, volume of the pump, volume occupied by the lobes, pressure across the inlet and exhaust port, and the time of operation etc. It is capable of handling large amount of gas compared to other vacuum generating pumps because other high vacuum pump requires a roughening pump. We can obtain vacuum in the range of $1*10^{-02}$ Torr to $5*10^{-04}$ Torr and its pumping speed is in the range of 10^{04} to 10^{06} liter/min with commercially available roots blower pumps depending on the size of the blower.

At atmospheric pressure when air has high viscosity, we cannot run this pump directly otherwise large amount of energy will be dissipated in heat generation. To overcome this first we run piston pump or water jet pump to reduce the pressure level at around 0.1 bar.

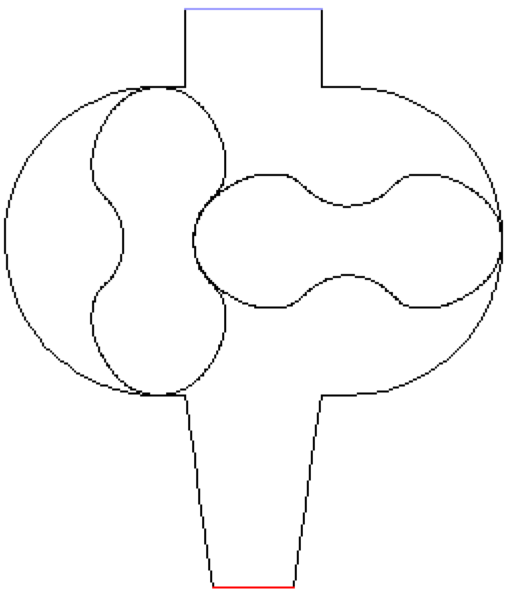

Figure 1.3: An outline geometry of Roots Blower Vacuum Pump.

1.1.3 APPLICATIONS, ADVANTAGES AND DRAWBACKS:

1.1.3.1 Applications:

- Roots Blower is an important device used **in Cryogenics**. It is used to create rough vacuum of the order of 10^{-04} Torr which is essential to generate HV, VHV or UHV because high vacuum devices such as Diffusion Pump, Ion Pump, Turbo Pumps, Cryo-pumps etc. cannot run directly without achieving the above said vacuum level.
- **In Cryogenics** it can be used to transfer fluids (liquid or gas) like LOx LN_2 LHe.
- **In Electrical & Electronic industries** like MEMS, Nanotechnology, Semiconductor fabrication it is used to generate moderate vacuum and also to transfer material from one section to another.
- **In Chemical Plants** like oil and refineries it is used to transport fluids, in food and beverages industries it can be used for both purposes fluid pumping as well as for moderate vacuum generation. It is also used in Cement industry for pneumatic conveying and for fluid pumping.
- **In medicine** it is used for fluid transfer (pulp, gas, liquid). Vacuum is needed in packaging of medicine so as not to contaminate with atmospheric air.
- In water treatment plant.
- Aeration in effluent treatment plant.
- Aquaculture aeration etc.

1.1.3.2 Advantages:

- Suitable for both liquids and gases.
- Low cast device, simple in construction and requires less maintenance.
- Tough body hence less vibration at optimal speed.
- Power transfer is maximum due to prime mover is directly connected to the rotor shaft.
- No contact between Rotor-Rotor and Rotor-clearance hence no tear wear due to friction.
- No frictional losses due to non-contact type construction.
- Minimum leakage in the reverse side results in large volumetric flow.
- Inside of the device is lubrication free.
- Ease of operation, highly reliable, long life of operation.

1.1.3.3 Drawback:

- Vacuum generation capability is limited to a level of 10^{-04} Torr.
- It cannot run at very high speed otherwise vibration will be high and so it can harm the foundation.
- Oil and grease are used in bearing of the shaft due to this oil vapor may enter into the chamber and can contaminate the fluid.
- It cannot be used for slurry handling purposes.
- After every revolution it transfer certain amount of fluid outside of the blower if the pipe, handling this fluid, is blocked then there is pressure rise drastically within the blower chamber that can damage and cause erosion in the machine.

1.1.4 MATERIALS:

For manufacturing the Roots Blower different materials like Cast Iron, Aluminum, Steel, Stainless Steel or ductile Iron can be used.

- **Casing:** Generally Cast Iron is used; Aluminum or Steel can also be used to increase the strength of the blower equipments. In this work Aluminum is used. Aluminum has higher thermal conductivity hence it has higher heat rejection capacity into atmosphere and so suitable for Cryogenic utility.
- **Rotor:** We can use Alloy material, Aluminum, Carbon Steel and Steel as Rotor material. Steel is the Rotor material in the work.

1.1.5 PUMP CHARACTERISTICS

Performance characteristics of the pump can be explained by geometry, clearance and inlet – outlet cross-section of the blower in the following manners:

- **Geometry:** The volumetric flow capacity of the blower greatly depends on the gap (empty space) inside the Roots Blower. If the geometry of the rotor is wide the flow volume will be low on the other hand if the same is of narrow design then there would be more empty space and hence the flow volume will be high.
- **Clearance:** It is important to maintain clearance between case and rotor, between rotor and rotor so that the losses due to frictional force can be minimized. If there is no clearance, mechanical parts will make contact as a result rotational speed will become less than the intended speed and this reduced amount of speed will be dissipated in the form of unwanted heating of the equipment and surrounding, tear-

wear will also occur, consequences can be severe to the foundation of the blower due to huge amount of vibration.

- **Inlet –outlet cross-section:** It is another parameter playing a vital role in the flow analysis of the roots blower. For the mouth piece of inlet equal to the distance between the two rotor axis (centre) the volumetric flow is maximum but at the same time back flow is also increases. And if (as in the CFD simulation in this project work) inlet cross section is reduced by 0.6 inches from both the rotor side then volumetric flow is reduced by small amount but back flow through the blower is minimized by large amount.

Pump specifications: Pumps are specified with the following parameters:

- Volumetric flow rate.
- Inlet port or suction pressure.
- Outlet port or discharge pressure.
- Temperature at inlet/outlet side.
- Optimal speed of operation.
- Volume and types of the gas in the region of operation.

1.1.6 PERFORMANCE MEASURES OF A VACUUM PUMP

Pumping Speed: is the volumetric flow rate from the inlet portion of a vacuum pump. It is considered as the factor of the inlet pressure of the pump. It often measured in m^3/sec, m^3/h, and L/sec and L/min. Pump speed of a particular pump is not same for all the fluid, it varies as type of fluid varies. For example, Momentum transfer and Entrapment pumps have more volumetric efficiency on certain gases than others. It can also be concluded that the volumetric flow rate will also vary with the chemical composition of the remaining gases into the chamber.

Throughput: Throughput implies multiplication of the pumping speed and gas pressure at the inlet of the chamber, and it is measured in the units of Pressure∗Volume/unit time. It is equivalent to the number of gaseous particle that are being pumped at the time rate, and hence it is also the volumetric mass flow rate of the pump.

1.1.7 THE IMPORTANCE OF THE ROOTS BLOWER PROFILE

Rotor profile generation is the most essential part of the roots blower pump. It is because that the volumetric flow through the blower is solely dependent on the volume of the shell of the blower and the volume of the rotor profile. Hence we can say that if the cross section of the rotor will small then it covers minimum area and hence according to it's with it will acquire least volume so that flow volume will be maximize. It has also small sealing so that it leakage flow should be minimized.

Its volumetric efficiency increases as leakage become shorter and flow is high. The rate of volumetric flow through the blower is the algebraic sum of the flow outside the blower and leakage through the clearances.

1.2 LITERATURE REVIEW

Several research work have been found on Roots Blower Vacuum Pumps such as Flow Analysis through Roots Blower (Usher S., Celik I. 1980), clearance analysis and leakage flow of a multi recompression heater (Joshi, M., Ashish 2006) screw type positive displacement machines like screw pumps (Nakashima et al., 2006; Räbiger et. al., 2008; Cheng et al., 2012; etc.), screw compressors (Fleming et al., 1995; Huagen et al., 2004; Ferreira et al., 2005; Paepe et al., 2005; etc.) and vacuum pumps (Gagg et al., 2007; Dong et al., 2011; Grzebyk et al., 2011; etc). In spite of the wealth of papers on screw type positive displacement machines, few are related to root blower (Chyang et al., 2002; Mason et al., 2007; Márquez et al., 2009; etc.). Among those, very few are on the optimization of profile of rotor in root blowers. Several attempts have been made to design the geometry of the rotor of root blower using single circular arc (Tsay, 1987) or using an involute (Hsieh and Meng, 1989) or using hypocycloid or epicycloid (Chiu, 1994) or a combination of five arc lobe in cross sectional form (Wang et al., 2002). Mathematical models have been derived by Holmes (1978) and Litvin (1994) the cross section of the rotor can be of any type namely arc, involute or cycloid. An addendum tooth profile had been proposed by Tsay and Chen (1998) having only one lobe in the circular arc type. In this work, the geometry formation, area, working efficiency, tooth cutting have studied for different number of rotors like 2 rotors, 3 rotors, and also or 4 rotors. Kang and Hsieh (2000) calculated the performance and efficiency for addendum rotors for this he had used the extended cycloid and also circular-cycloid geometry. Good area efficiency was found by Fang (1992) using addendum and dedendum composed of four arcs in circular design. Later, Yao et al. (2005) proposed a 3 rotor involute design having mainly three arcs off which 2 are of circular type and the third one was of involute type. This newly designed tooth of the blower has higher efficiency in fluid flow and also was good in pressure gradient term. Further Hsieh and Hwang (2008) introduced cycloid curve in the extended form with erratic trochoid. In their proposed structure they used 3rd, 5th and 7th order of polynomials and sinusoids. By using this method higher volumetric efficiency has obtained in comparison to those previously designed. Recently, numerical methods have been implemented by Zhang (2008) to study the internal flow field, characteristic of air flow fluctuation and influence of rotor profile on the performance of the root blower. The rotor profile and casing structure of Roots blower have also been optimized by him for increasing the volumetric efficiency, reducing the noise and exhaust temperature.

1.3 GAPS IN THE LITERATURE

Though few attempts have be made on profile optimization of rotors of roots blowers numerically for increasing the volumetric efficiency, reducing the noise and exhaust temperature of Roots blower, according to the best of the author's knowledge, no automatic hybrid computational methodology to optimize the rotor profile and hence improve the performance of Roots blowers is been formulated. In present work, a robust numerical study is made to predict the flow characteristics and the overall efficiency of the device. Mathematical equation for the rotor/lobe geometry is studied and for optimization purpose some variation in the main design has been incorporated with independent constant values. A Computational Fluid Dynamics simulation has been done assuming steady state to show the variation in flow parameter. The objective of this work was to study the performance characteristics such as the rotor dimensions. By optimization of rotor/lobe profile, the desired characteristics have been studied.

1.4 OBJECTIVE OF THE CURRENT WORK

In present work, numerical study is made to predict the flow characteristics and the overall efficiency of the device. Mathematical equation for the rotor/lobe geometry is studied and for optimization purpose some variation in the main design has been incorporated with independent constant values. A Computational Fluid Dynamics simulation has been done assuming steady state to show the variation in flow parameter. The objective of this work is to study the performance characteristics such as the rotor dimensions. By optimization of rotor/lobe profile, the desired characteristics have been studied.

CHAPTER 2: Problem Formulation

To meet the objective and aims as described in chapter 1, how the present problems are formulated, are described in this chapter. The Rotor profile has been varied in 4 different ways. By varying the width of the west of the Rotor of different profiles, have been generated and used for numerical study. The details about the generation of profile are given below

2.1 DESIGN PARAMETER

The rotor/lobe of the roots blower vacuum pump is comprises three curves, of which two are circular arc and third is convex arc that is an involutes curve. The convex involutes curve is constructed by varying angle γ according to angle Φ, and plotting the corresponding values. These points depend on $R_L$value, the radius of the lower circle. To construct the total involute profile/curve, the following parametric equations [Joshi, M. Ashish et. Al. (2006)] has used.

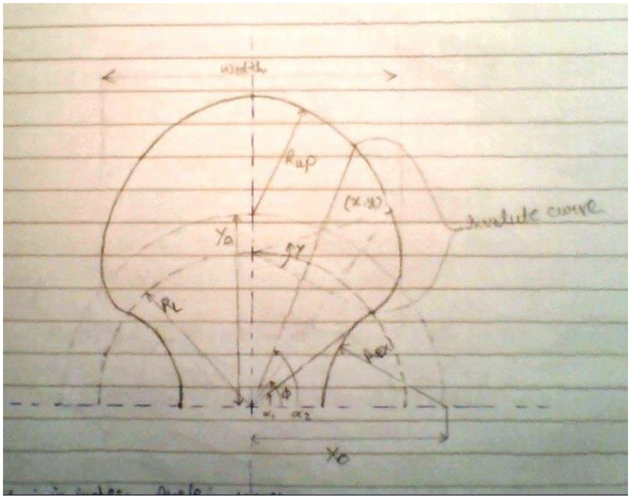

Figure 2.1: Diagram of Rotor Profile

Curve 1: **If $\Phi = [0, \alpha_1]$**

$$X(\Phi) = R_{ex} \cos\{\pi - (5\Phi/4)\} + X_0,$$

$$Y(\Phi) = R_{ex} \sin\{\pi - (5\Phi/4)\}$$

Curve 2: **If $\Phi = [\alpha_1, \alpha_2]$,**

$$X(\Phi) = K_{21}(\gamma)\cos(-\alpha_1) + K_{22}(\gamma)\sin(-\alpha_1),$$

$$Y(\Phi) = K_{22}(\gamma)\cos(-\alpha_1) + K_{21}(\gamma)\sin(-\alpha_1)$$

Here;

$$K_{21}(\gamma) = R_L\{\cos(\gamma) + \gamma.\sin(\gamma)\},$$

$$K_{22}(\gamma) = R_L\{\sin(\gamma) - \gamma.\cos(\gamma)\}$$

As Φ goes from 40^0to70^0, the angle γ tracing the convex curve moves from 0^0 to 86.4708^0. From the involutes curve equation of the circle the relation between angle Φ and γ is as follows:

$$\Phi = \tan^{-1} [\{\sin(\gamma) - \gamma.\cos(\gamma)\} / \{\cos(\gamma) + \gamma.\operatorname{Sin}(\gamma)\}]$$

Curve 3: **If $\Phi = [\alpha 2, \pi/2]$,**

$$X(\Phi) = R_{up} \operatorname{Cos} \left[\frac{52.6\pi(\theta-\alpha_2)}{180(\frac{\pi}{2}-\alpha_2)} + \frac{37.47\pi}{180}\right]$$

$$Y(\Phi) = R_{up} \sin \left[\frac{52.6\pi(\theta-\alpha_2)}{180(\frac{\pi}{2}-\alpha_2)} + \frac{37.47\pi}{180}\right] + Y_0$$

There are four cases of width of the west of Rotor profile which we will study for the analysis purpose of different flow parameters. We will change only the width of the rotor for study, keeping all other independent constant the same.

2.1.1 CASE 1: WHEN R_{EX}, LOWER CIRCULAR ARC IS 0.036 METER (1.44 INCHES) AND THE WIDTH OF THE WEST OF THE ROTOR IS 0.020375 METER OR 0.815 INCHES.

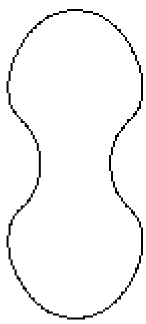

Figure 2.2: Rotor Profile 1 with Rex = 0.815 inch.

In the above Figure 2.2 Rotor profile 1 has been shown and the values are as follows:

Linear dimensions are in meters while angles are in radian and degrees.

Rex= 0.036

Rup= 0.03425

R_L= 0.04478

Y_0= 0.055975

α_1 = 4π/18

α_2= 7π/18

γ = 0^0 to 86.4708^0

2.1.2 CASE 2: WHEN R_{EX}, LOWER CIRCULAR ARC IS 0.03625 METER (1.45 INCHES) AND THE WIDTH OF THE WEST OF THE ROTOR IS 0.020125 METER OR 0.805 INCHES.

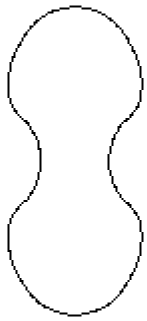

Figure 2.3: Rotor Profile 2 with Rex = 0.805 inch.

In the above Figure 2.3 Rotor profile has been shown and the values are as follows: Linear dimensions are in meters while angles are in radian and degrees.

Rex= 0.03625

Rup= 0.03425

R_L= 0.04478

Y_0= 0.055975

α_1 = 4π/18

α_2= 7π/18

γ = 0^0 to 86.4708^0

2.1.3 Case 3: When R_{ex}, lower circular arc is 0.03917125 meter (1.56685 inches) and the width of the west of the rotor is 0.01720375 meter or 0.68815 inches.

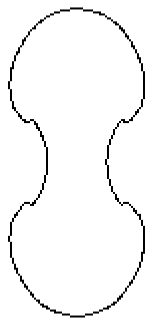

Figure 2.4: Rotor Profile 3 with Rex = 0.68815 inch.

In the above Figure 2.4 Rotor profile 1 has been shown and the values are as follows:

Linear dimensions are in meters while angles are in radian and degrees.

Rex= 0.03917125

Rup= 0.03425

R_L= 0.04478

Y_0= 0.055975

$\alpha_1 = 4\pi/18$

$\alpha_2 = 7\pi/18$

$\gamma = 0^0$ to 86.4708^0

2.1.4 Case 4: When R_{ex}, lower circular arc is 0.0358 meter (1.432 inches) and the width of the west of the rotor is 0.020575 meter or 0.823 inches.

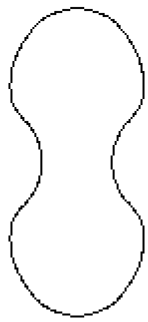

Figure 2.5: Rotor Profile 4 with Rex = 0.823 inch.

In the above Figure 2.5 Rotor profile 1 has been shown and the values are as follows:
Linear dimensions are in meters while angles are in radian and degrees.

Rex= 0.0358

Rup= 0.03425

R_L= 0.04478

Y_0= 0.055975

$\alpha_1 = 4\pi/18$

$\alpha_2 = 7\pi/18$

$\gamma = 0^0$ to 86.4708^0

2.2 CLEARANCE IN ROOTS BLOWER

There are two, symmetrical rotors in the Roots Blowers, rotor repeats its position after every 180^0, and after every 90^0 the clearance data is repeated, further both rotors are symmetrical about 45^0. The coordinates can be found by combining rotational and translational transformation of the coordinates. There is clearance between rotor-rotor and between rotor-casing to make non contact type machine so that losses due to friction such as heating, tear-wear can be minimized and also to maintain the speed of rotation.

To calculate the minimum clearance, we calculate the minimum occupied space in-between the both rotors. Among all those distances the minimum distance is the minimum clearance between both rotors. In this study,

2.2.1 In case 1(Wr=0.815 inches): the clearance between rotors is 0.013 inch (0.000325 meter) and between rotor-casing is 0.014 inch (0.00035 meter).

2.2.2 In case 2(Wr=0.805 inches): the clearance between rotors is 0.023 inch (0.000575 meter) and between rotor-casing is 0.014 inch (0.00035 meter).

2.2.3 In case 3(Wr=0.68815 inches): the clearance between rotors is 0.13985 inch (0.00349625 meter) and between rotor-casing is 0.014 inch (0.00035 meter).

2.2.4 In case 4(Wr=0.823 inches): the clearance between rotors is 0.005 inch (0.000125 meter) and between rotor-casing is 0.014 inch (0.00035 meter).

CHAPTER 3: Methodology

In This Chapter Overview On Cfd Package And Use Of It On Problem Formulation In Ansys Have Been Studied.

3.1 GEOMETRY FORMATION IN ANSYS

3.1.1 GENERATING THE GRID

In ANSYS there are two methods of generating the grid that are “bottom to top” or “top to bottom” in the manual. In this vertices can be created, which are connected next to make edges. Edges are connected next to generate the face and faces are used to create volume of closed systems.

3.1.2 VERTEX

In Ansys there is facility of drawing the desired geometry. There are options to point co-ordinates in 2-D or in 3-D. So we can generate co-ordinate system according to our requirement In Vertex section we can notify the co-ordinates of the point of corners in the design geometry.

3.1.3 EDGES

In The Edges section there is option to generate straight line, circle, ellipse, nurbs, arc, conic fillet etc. As per our requirement we can use among those options to draw the geometry of our interest. As in Vertex we have generated the co-ordinate system of the required design, further need to connect so that a Skelton diagrams can be generated. In the Edges section by selecting the consecutive co-ordinates we have drawn the line diagram of the design and the half circular arcs.

3.1.4 FACES

Facing is done after Edge formation, so that a complete geometry of the design can be made by connecting all the edges. In the face section we can add, subtract or merge the 2 or more faces. We can directly generate the whole geometry in the face form directly if the geometry is in the simple form of circle, square, ellipse or in the form of rectangle.

3.1.5 MESH

In Mesh section, grids in the each geometry are generated. We have options to make grids in the geometry in the sense that we can select entire geometry at once and specify the element type and spacing between the two consecutive grids. Or we can do the same in segmented form by selecting growth ratios in each faces. It divides the enclosed area or volume in number of small grids that helps us to analyze the working phenomenon accurately. Its node value gives the exact condition of any parameter in the simulation part.

3.1.6 BOUNDARY CONDITIONS

The whole design (geometry) is further divided into zones from where we can specify the boundary condition of the design. In this section inlet, outlet, wall boundary conditions etc. can be assigned to the walls of geometry. Materials continuum are also defined in this section, like in the current work both Rotors have assigned as solid continuum and the third section which is vacant, is assigned as Air continuum.

3.1.7 SAVE AND EXPORT

After the boundary condition, the generated profile is exported for further simulation in the Ansys. We can export the generated file in Mesh, Catia, STEP, IGES, Parasolid or ACIS file format.

3.2 NUMERICAL SOLVING TECHNIQUE

Generally Conservation of mass, momentum and Energy (if required) equations are solved by ANSYS. Scalar quantities such as turbulence also are dealt with ANSYS. In the CFD simulation generally we use the control volume methods to analyze the flow problems. To do this we can assume the following steps:

- First we make divisions in the geometry (continuum) by generating grid system (fine or coarser).
- Apply the equations governing the fluid flow through the system on each discrete control volume and then integrate them into one.

3.2.1 SOLVING THE PROBLEM

In ANSYS there are two options for numerical methods by which we can solve the problem:

- Coupled method and
- Segregated method.

3.2.1.1 Coupled Method

In this method principal equations such as momentum, mass conservation, continuity and if required the energy equations are solved simultaneously. And for all other scalar quantities are sequential methods are used i.e. they are solved one by one. Since the principal governing equations are non-linear it needs lots of iteration before obtaining the converged solution. All iteration involves the following steps:

- In the iteration, properties of the fluid get updated every time based on the previous solution.
- The conservation equation like mass, momentum, continuity, energy (if required) and turbulence model are solved continuously in a coupled manner.
- In the process, sometimes, a check for convergence the solution is done.

The above said steps are repeated again and again until converged solution is obtained.

3.2.1.2 Segregated Method

In this method the main equations are solved sequentially i.e. one by one. And for all other scalar quantities are sequential methods are used i.e. they are solved one by one. Since the principal governing equations are non-linear it needs lots of iteration before obtaining the converged solution. All iteration involves the following steps:

- In this properties of the working fluid is updated based on the initialized or current solution.
- In a combination with updating the velocity, the momentum equations of u, v and w are solved for current values to calculate the pressure and mass fluxes in the flow field.
- There is a possibility that the velocity obtained may not follow the continuity equation at present values therefore a "Poisson type" equation is utilized to make correction in the velocity and pressure values.
- Some scalar equations like turbulence, radiation and energy can be solved by the previous values of the calculated data.

The above steps are continuously iterated until the converged solution is reached.

3.3 TURBULENCE REPRESENTATION

After attaining the steady state analysis of various parameters has been done like temperature rise, volumetric flow rate, rise in pressure and the velocity of fluid at outlet. The fluid flow area is considered the same at all cross-section hence a two dimensional analysis has done and results on various parameter mentioned above have taken and scaled using graph.

There are gaps Inside the blower shell, due to this when operating there exist drastic change in pressure. Therefore we used k-ω turbulence model. It gives precise result when the flow is within wall bounded conditions. In the simulation when converse the objective, we see two additional equations that are for k-ω.

3.4 CONVERGENCE OF THE PROBLEM

For the determination of the convergence of the present work, the residuals are monitored at every time steps. Residuals R in the finite volume solution for a certain cell and the N number of iteration, is the inequality of the finite volume transportation equation.

3.5 STEPS USED TO SOLVE THE PROBLEMS

The following steps are followed in solving the required problem:

- Generation of geometry and meshing the model.
- Export the mesh model in ANSYS.
- Open in ANSYS, for 2D model solving.
- Check the grid in ANSYS for positive volume or negative volume.
- If positive volume found then it's OK otherwise go back to the grid sizing or in face meshing option.
- Define the different parameter like solver, energy, viscosity, material, operating condition and boundary conditions etc.
- In solve option go to control, solution, initialize, monitors, residuals and then iterate the problem until it converges.
- Since it is a steady state problem hence it does not dependent on time.
- Check the result-plot in X-Y and write the report in .xls file format.

CHAPTER 4: Results and Discussion

Based on 2-D CFD model, the detail numerical results in terms of temperature contour, pressure contour, velocity contour and velocity vector for the 4 different cases have been extensively described in this chapter. The comparison between the Results has also been made here.

4.1 CASE 1: WHEN R_{EX}, LOWER CIRCULAR ARC IS 0.036 METER (1.44 INCHES) AND THE WIDTH OF THE WEST OF THE ROTOR IS 0.020375 METER OR 0.815 INCHES.

4.1.1 THE GENERATED SHAPE OF THE PROFILE AND MESH OBTAINED.

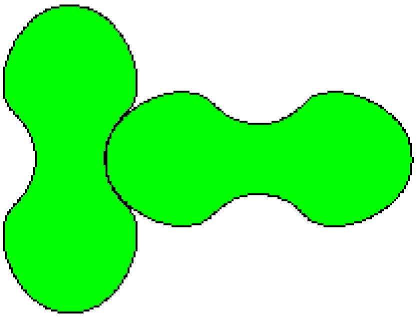

Figure 4.1: Meshing of the rotor profile 1

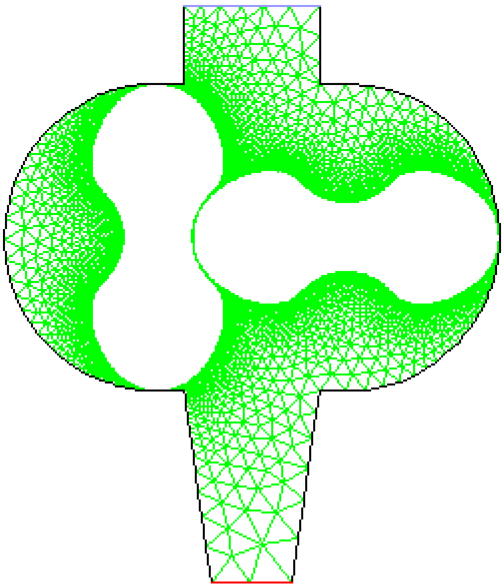

Figure 4.2: Meshing of the shell geometry 1

4.1.2 PRESSURE CONTOUR: The pressure contour for the rotor profile with Rex value 0.815 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.3.

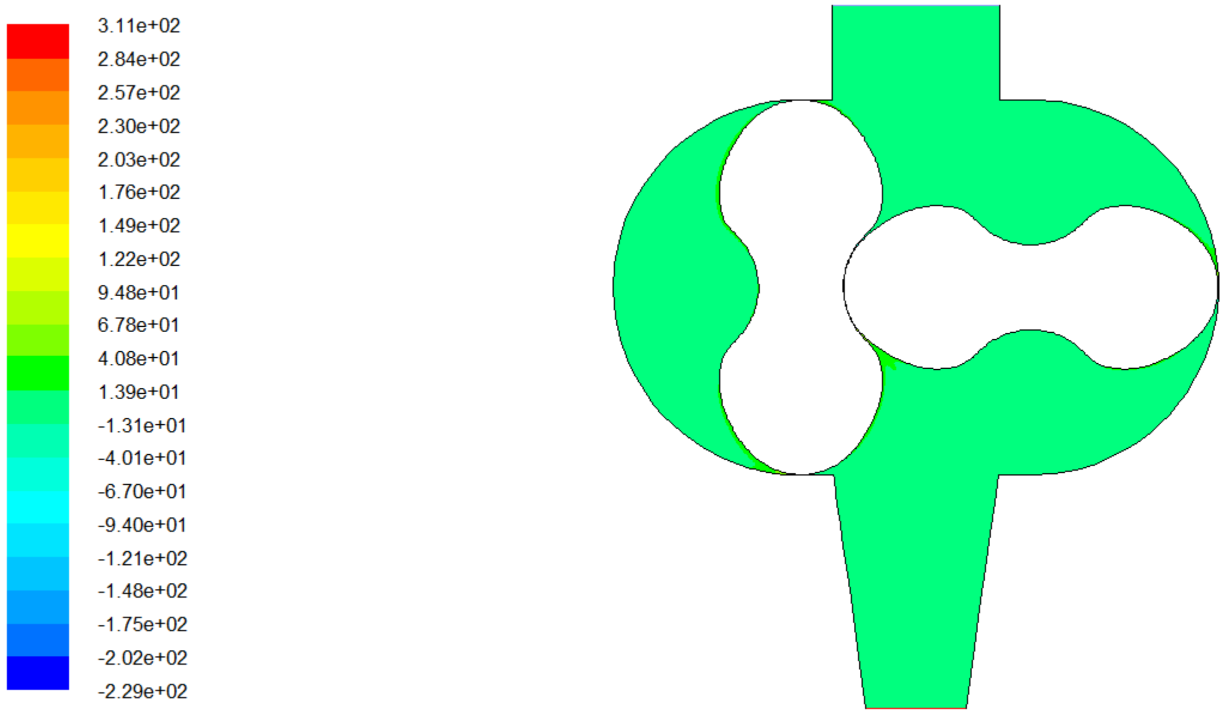

Figure 4.3: Pressure contour at speed 300 rad/sec with Rex value 0.815 inch.

4.1.3 VELOCITY CONTOUR: The velocity magnitude contour for the rotor profile with Rex value 0.815 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.4.

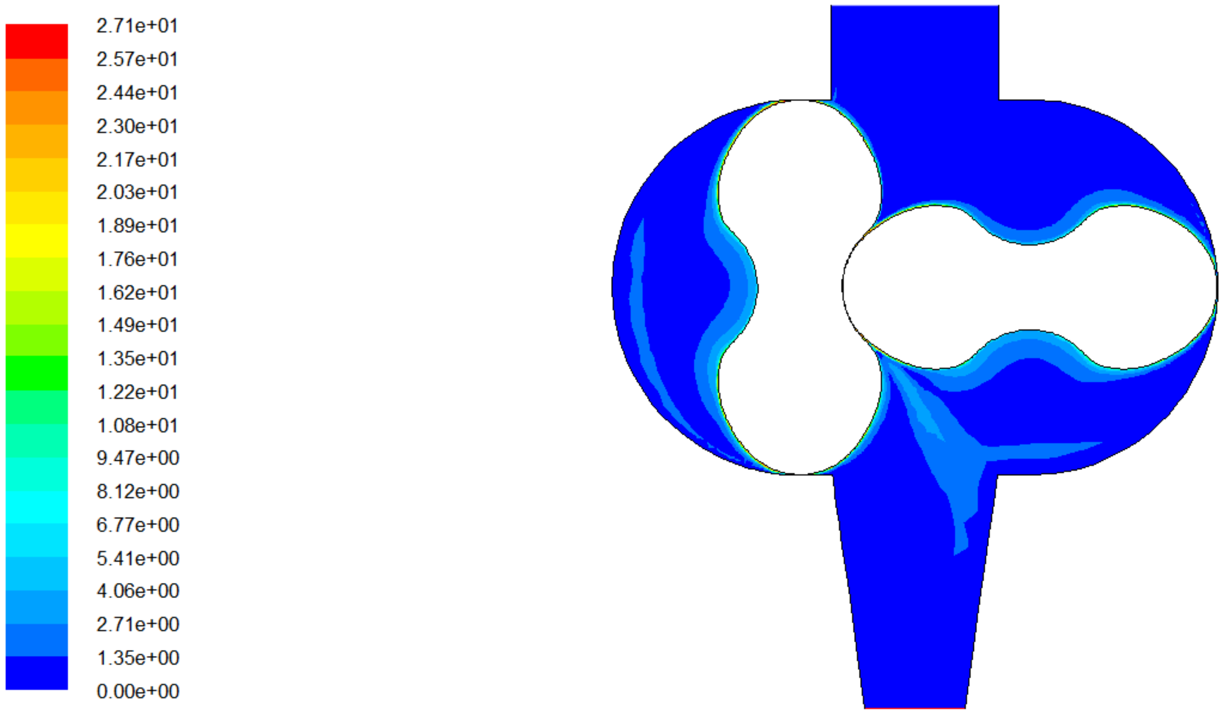

Figure 4.4: Velocity Magnitude contour at speed 300 rad/sec with Rex value 0.815 inch.

4.1.4 VELOCITY VECTOR: The Velocity Vector for the Rotor profile with Rex value 0.815 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.5.

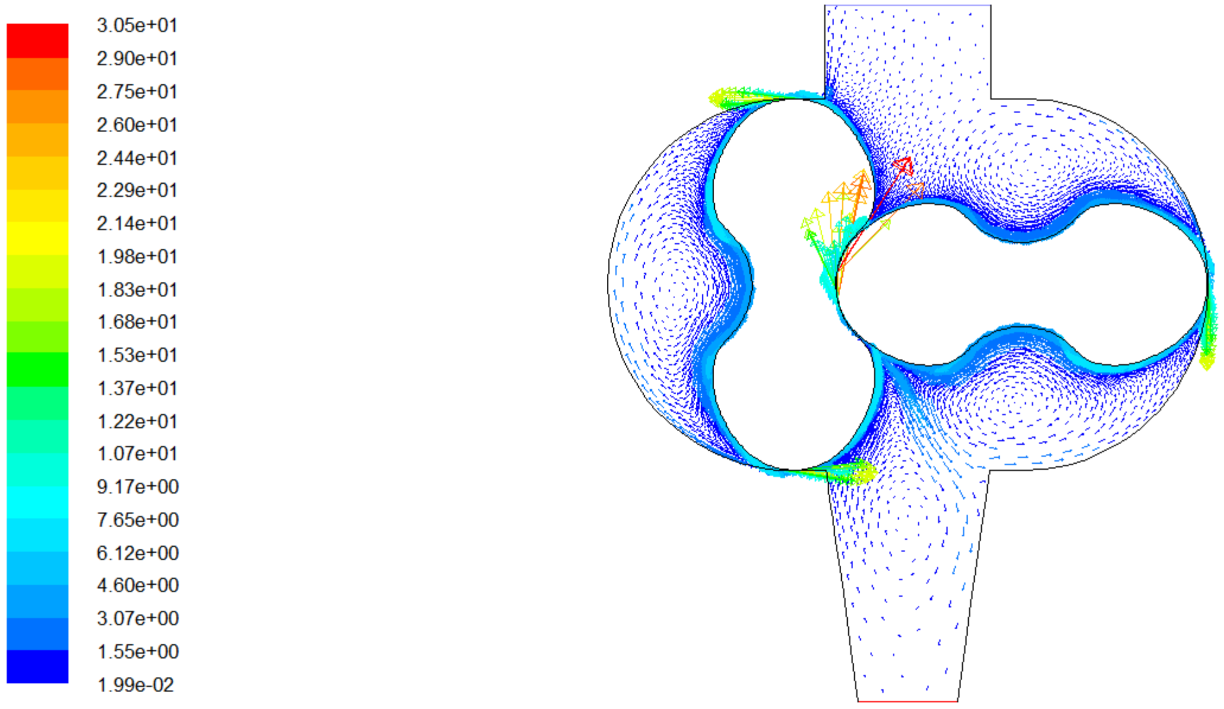

Figure 4.5: Velocity Vector at speed 300 rad/sec with Rex value 0.815 inch.

4.1.5 TEMPERATURE CONTOUR: The Temperature Contour for the Rotor profile with Rex value 0.815 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.6.

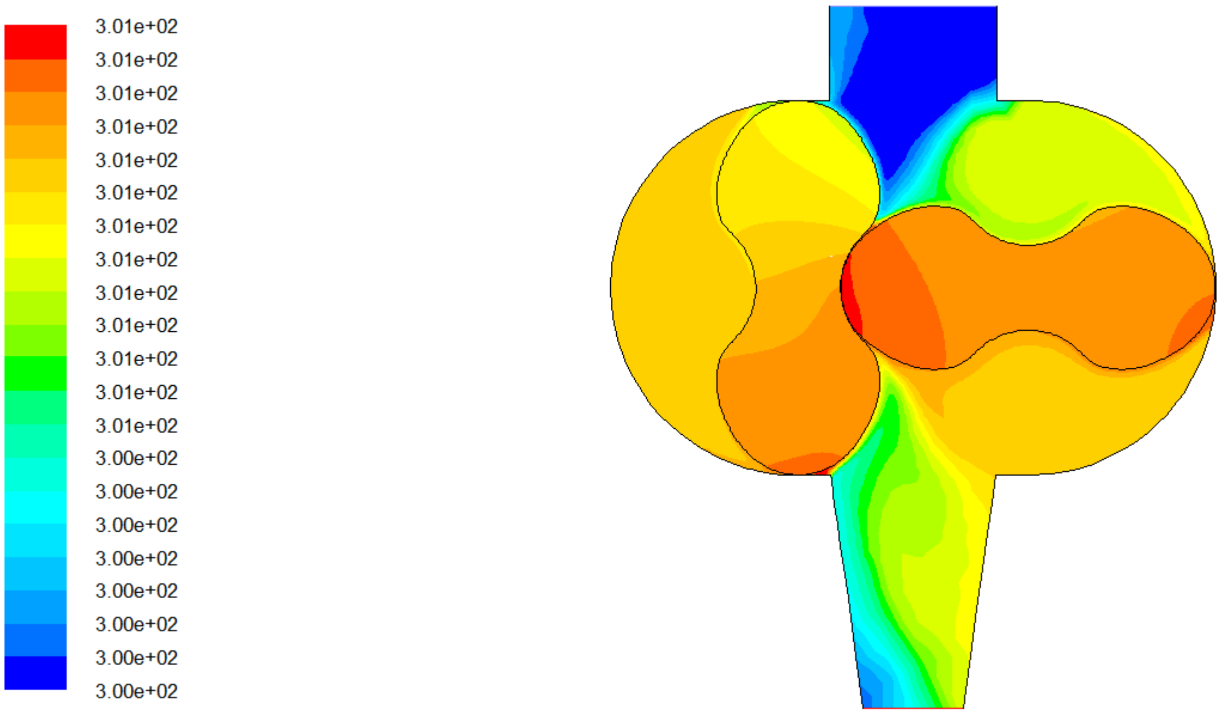

Figure 4.6: Temperature Contour at speed 300 rad/sec with Rex value 0.815 inch.

4.2 CASE 2: WHEN R_{EX}, LOWER CIRCULAR ARC IS 0.03625 METER (1.45 INCHES) AND THE WIDTH OF THE WEST OF THE ROTOR IS 0.020125 METER OR 0.805 INCHES.

4.2.1 THE GENERATED SHAPE OF THE PROFILE AND MESH OBTAINED.

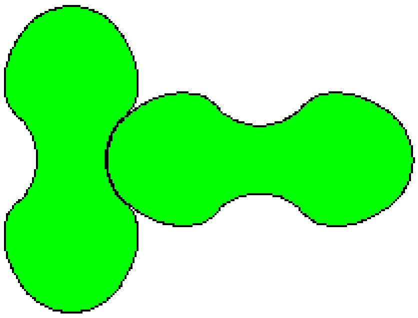

Figure 4.7: Meshing of the rotor profile 2

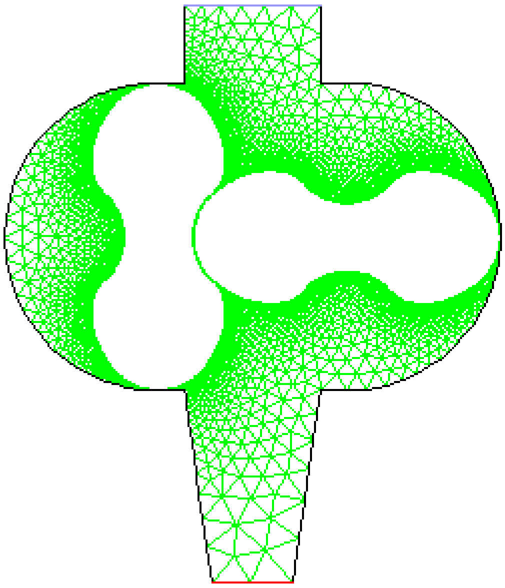

Figure 4.8: Meshing of the shell geometry 2

4.2.2 PRESSURE CONTOUR: The pressure contour for the rotor profile with Rex value 0.805 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.9.

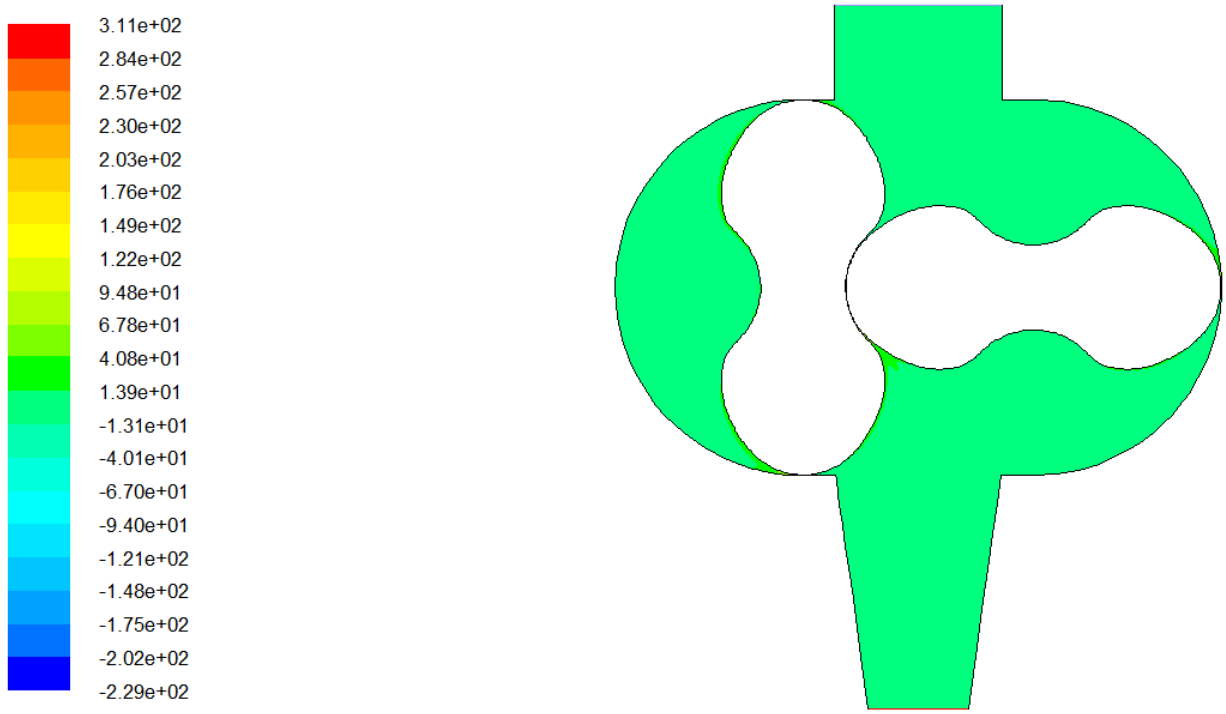

Figure 4.9: Pressure Contour at speed 300 rad/sec with Rex value 0.805 inch.

4.2.3 VELOCITY CONTOUR: The Velocity Magnitude Contour for the Rotor profile with Rex value 0.805 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.10.

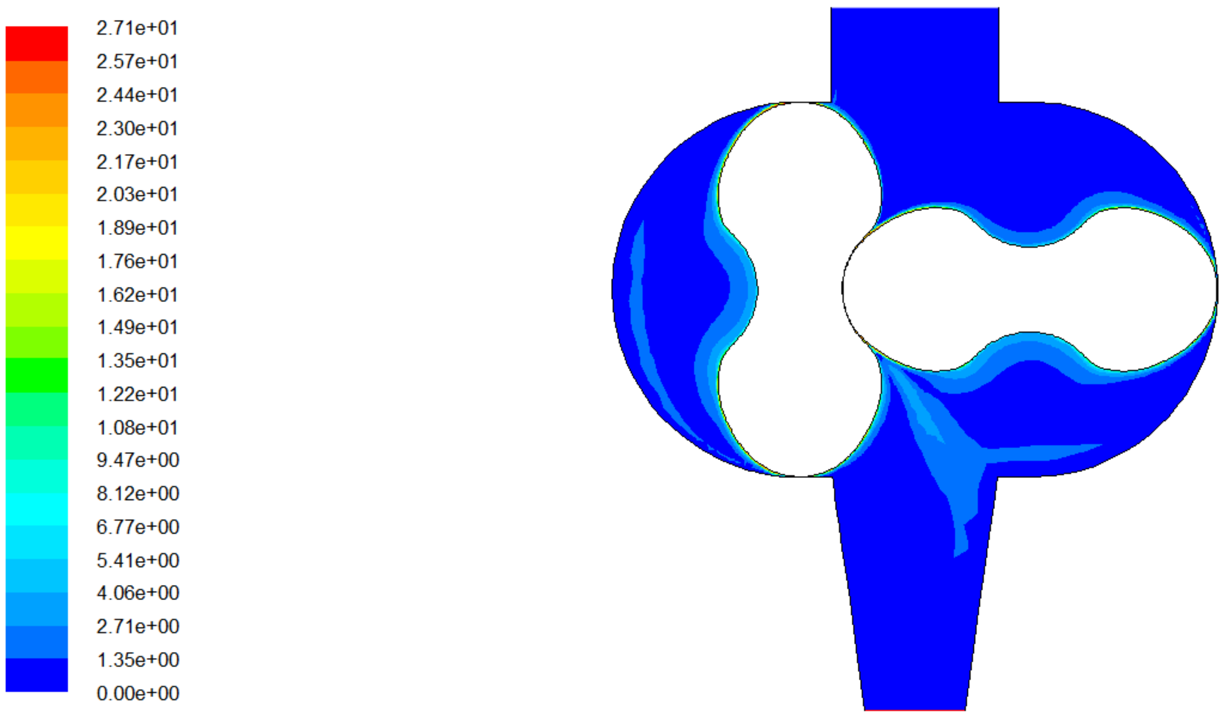

Figure 4.10: Velocity Contour at speed 300 rad/sec with Rex value 0.805 inch.

4.2.4 VELOCITY VECTOR: The Velocity Vector for the Rotor profile with Rex value 0.805 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.11.

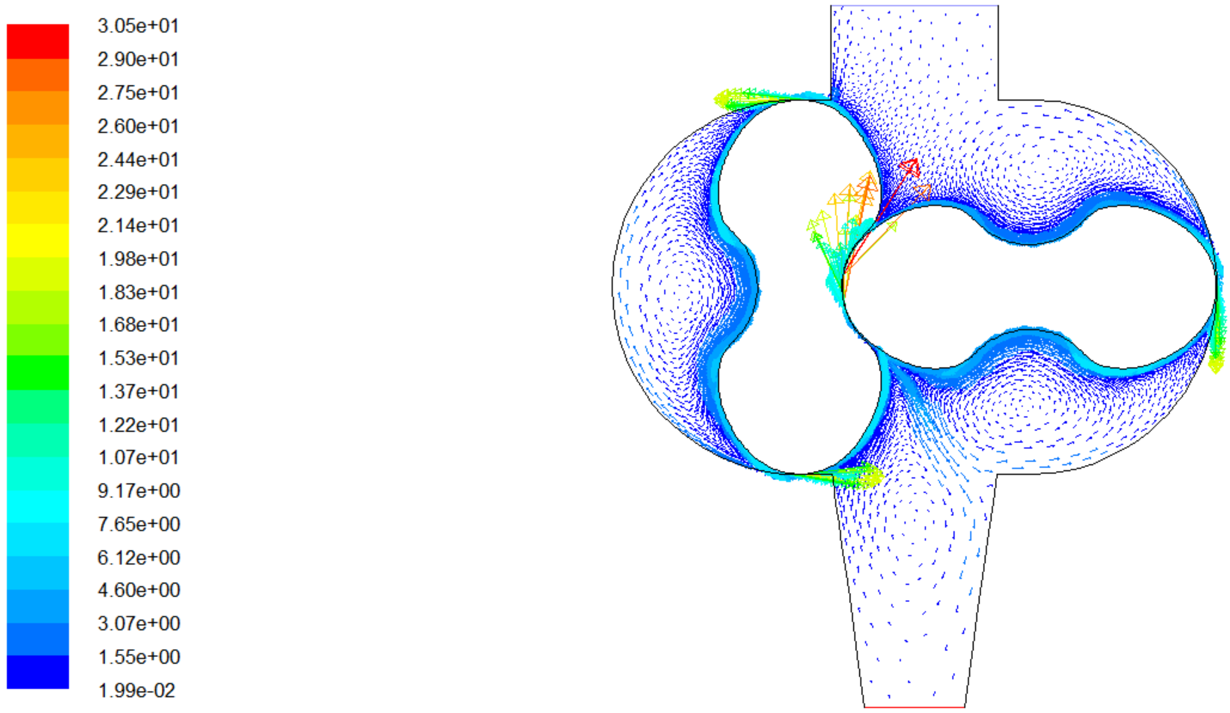

Figure 4.11: Velocity Vector at speed 300 rad/sec with Rex value 0.805 inch.

4.2.5 TEMPERATURE CONTOUR: The Temperature Contour for the Rotor profile with Rex value 0.805 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.12.

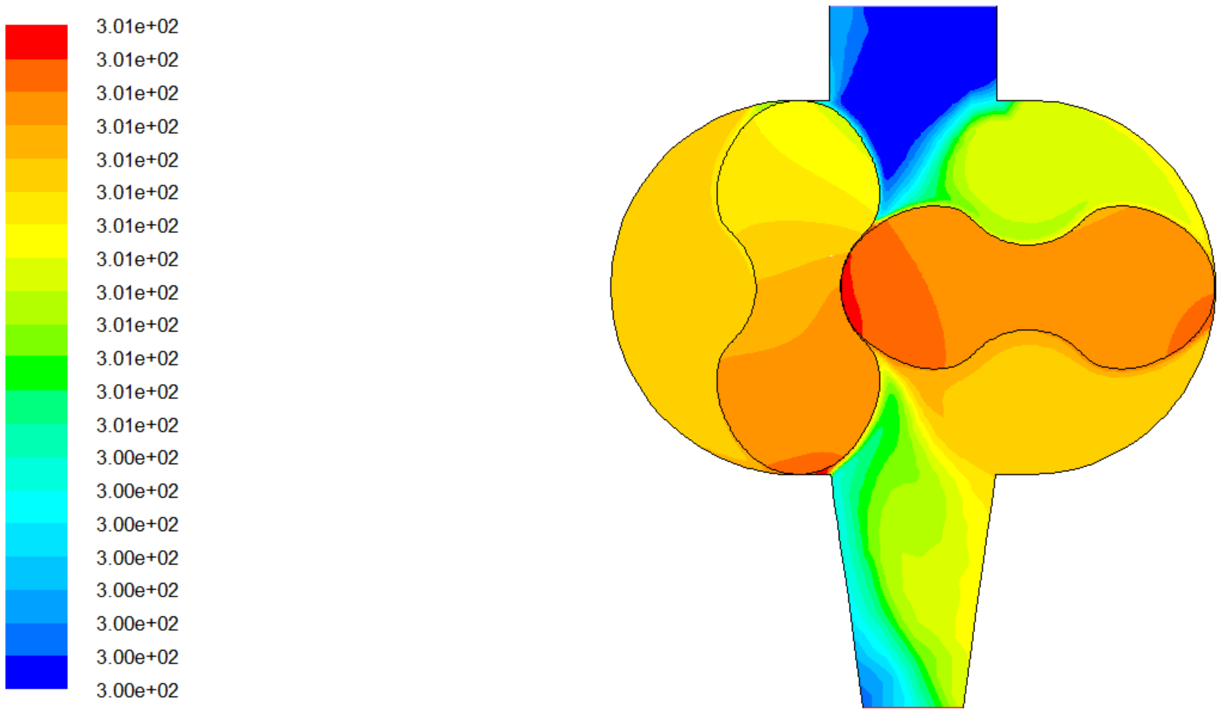

Figure 4.12: Temperature Contour at speed 300 rad/sec with Rex value 0.805 inch.

4.3 CASE 3: When R_{ex}, Lower Circular Arc Is 0.03917125 Meter (1.56685 Inches) And The Width Of The West Of The Rotor Is 0.01720375 Meter Or 0.68815 Inches.

4.3.1 THE GENERATED SHAPE OF THE PROFILE AND MESH OBTAINED.

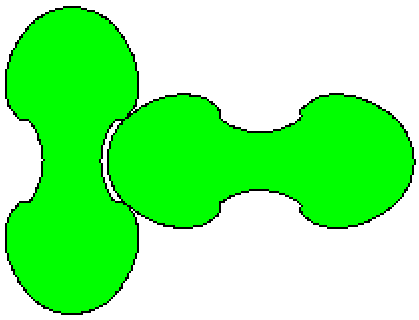

Figure 4.13: Meshing of the rotor profile 3

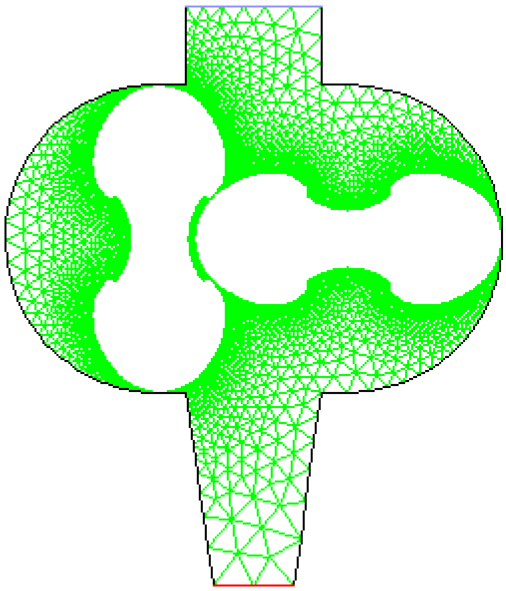

Figure 4.14: Meshing of the shell geometry 3

4.3.2 PRESSURE CONTOUR: The pressure contour for the rotor profile with Rex value 0.68815 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.15.

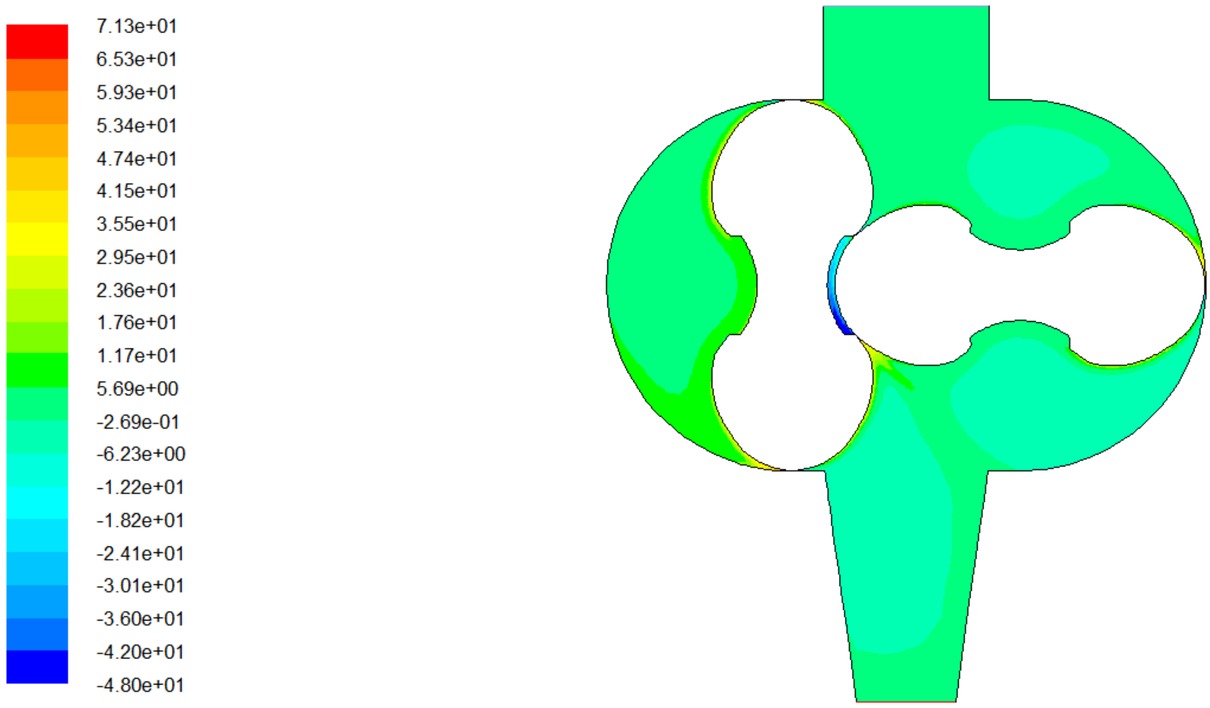

Figure 4.15: Pressure Contour at speed 300 rad/sec with Rex value 0.68815 inch.

4.3.3 VELOCITY CONTOUR: The Velocity Contour for the rotor profile with Rex value 0.68815 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.16.

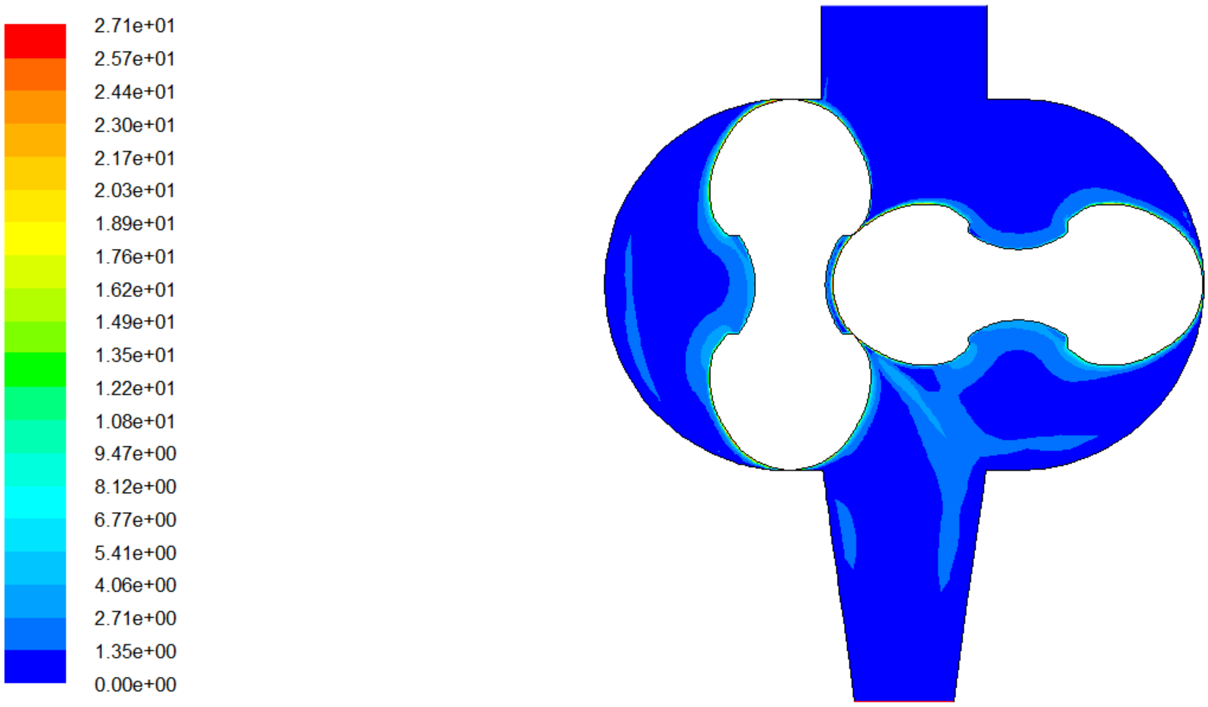

Figure 4.16: Velocity Magnitude Contour at speed 300 rad/sec with Rex value 0.68815 inch.

4.3.4 VELOCITY VECTOR: The Velocity Vector for the rotor profile with Rex value 0.68815 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.17.

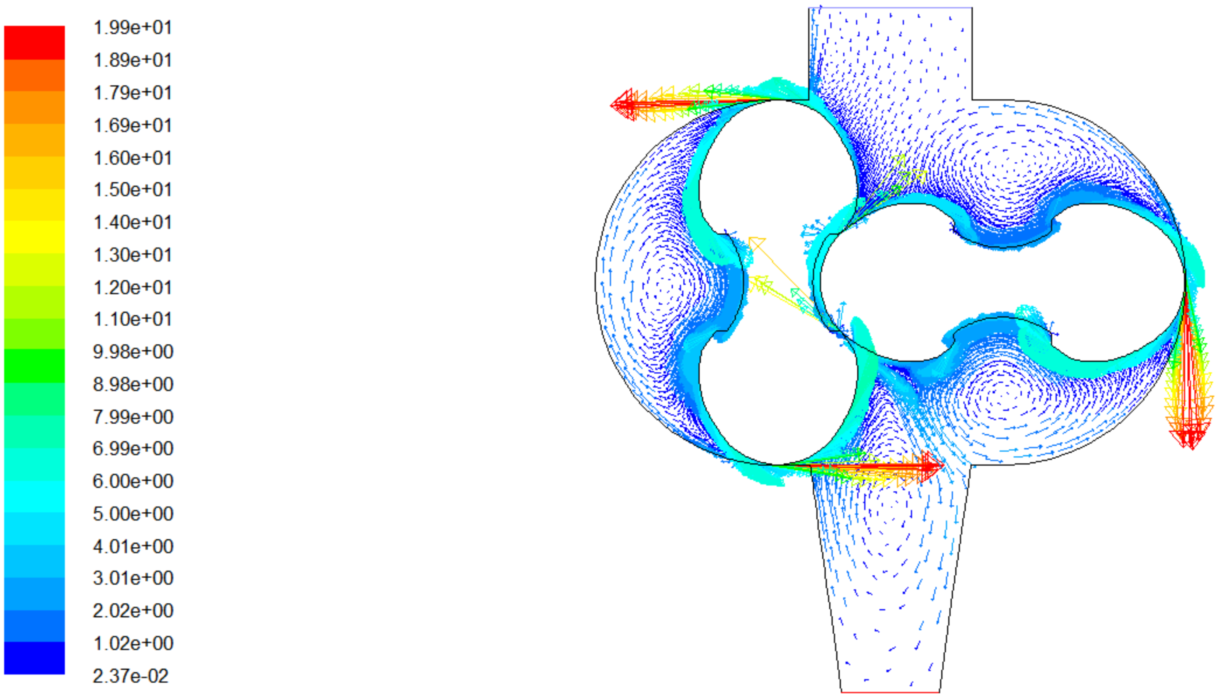

Figure 4.17: Velocity Vector at speed 300 rad/sec with Rex value 0.68815 inch.

4.3.5 TEMPERATURE CONTOUR: The pressure contour for the rotor profile with Rex value 0.68815 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.18.

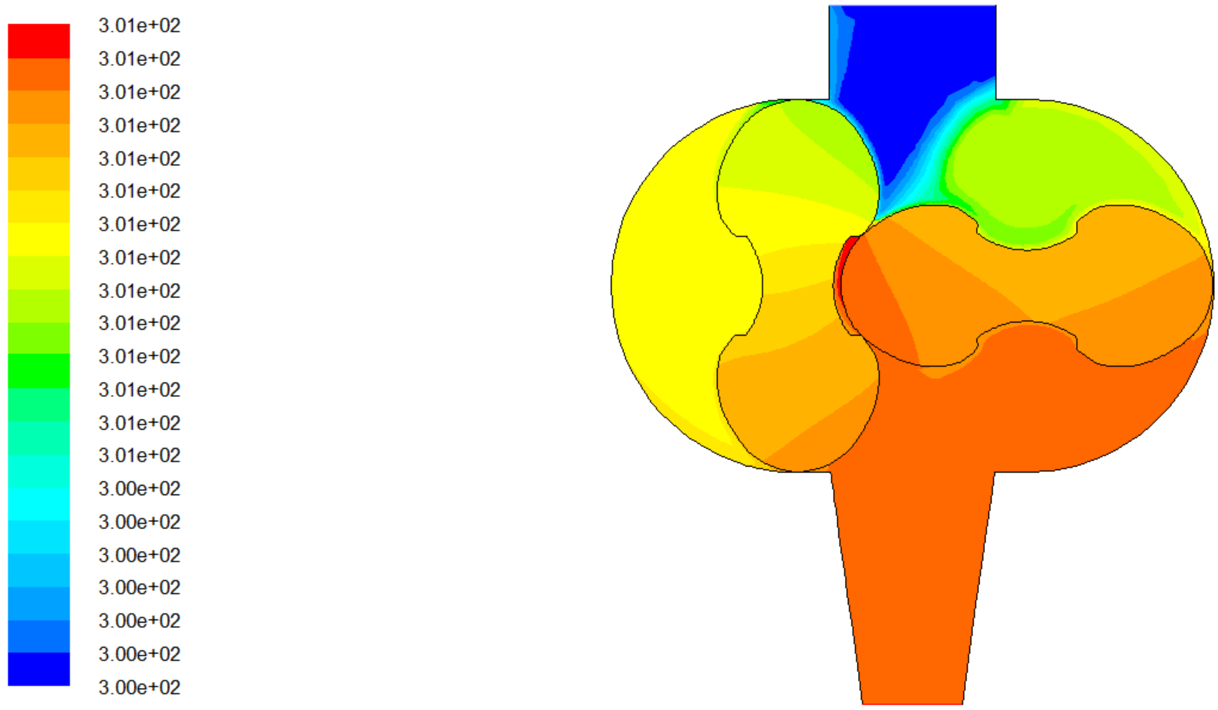

Figure 4.18: Temperature Contour at speed 300 rad/sec with Rex value 0.68815 inch.

4.4 CASE 4: WHEN R_{EX}, LOWER CIRCULAR ARC IS 0.0358 METER (1.432 INCHES) AND THE WIDTH OF THE WEST OF THE ROTOR IS 0.020575 METER OR 0.823 INCHES.

4.4.1 The generated shape of the profile and mesh obtained.

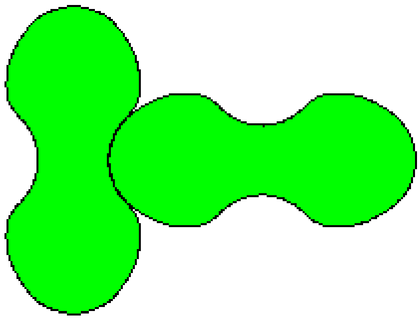

Figure 4.19: Meshing of the rotor profile 4

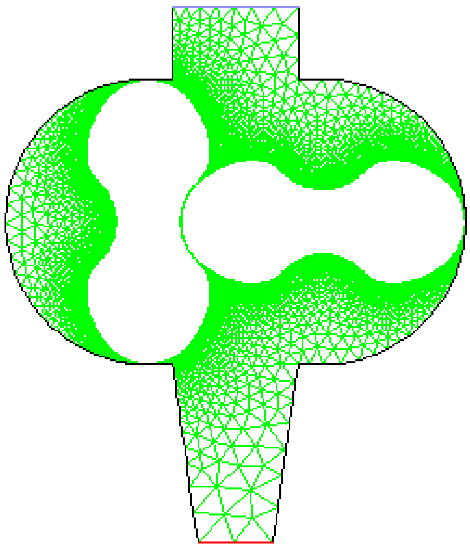

Figure 4.20: Meshing of the shell geometry 4

4.4.2 PRESSURE CONTOUR: The pressure contour for the rotor profile with Rex value 0.823 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.21.

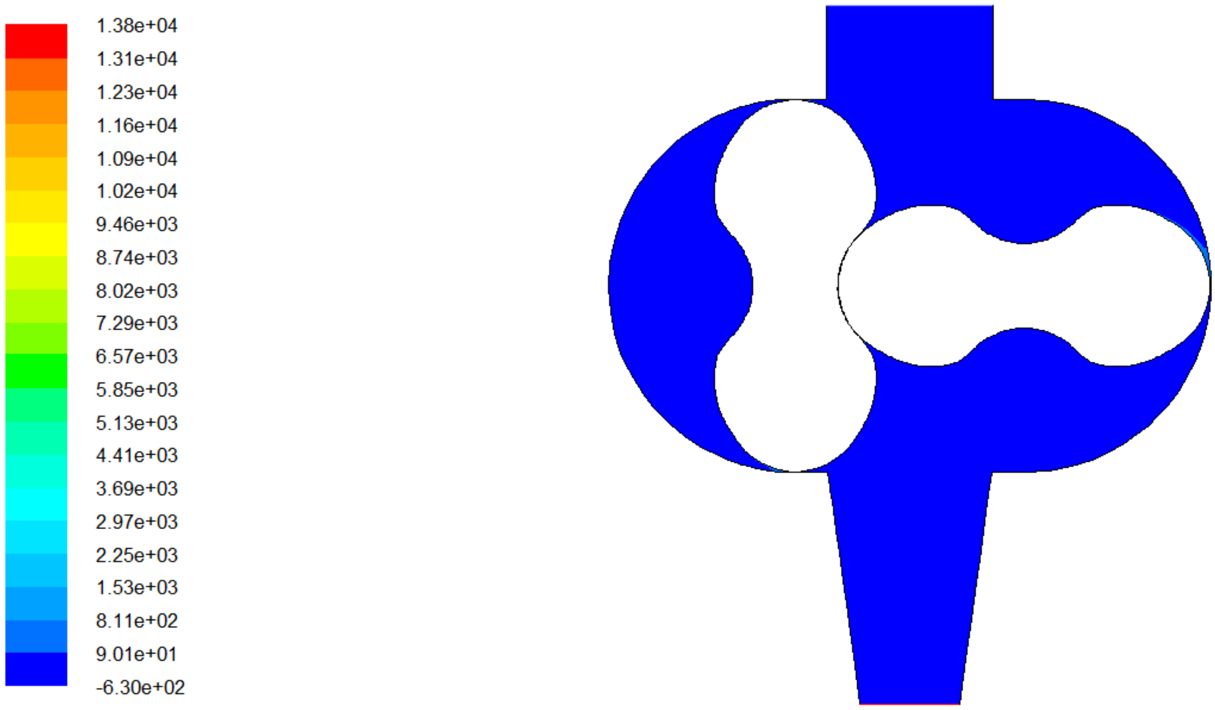

Figure 4..21: Pressure Contour at speed 300 rad/sec with Rex value 0.823 inch.

4.4.3 VELOCITY CONTOUR: The Velocity Magnitude Contour for the rotor profile with Rex value 0.823 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.22.

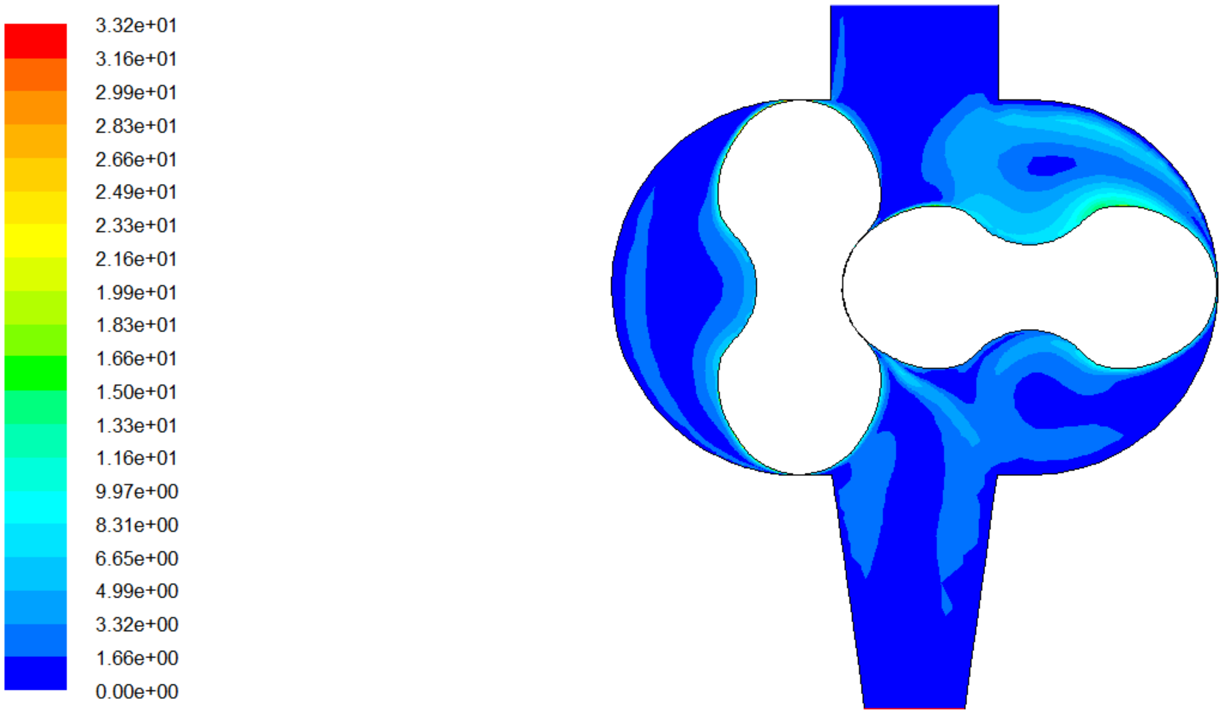

Figure 4.22: Velocity Magnitude Contour at speed 300 rad/sec with Rex value 0.823 inch.

4.4.4 VELOCITY VECTOR: The Velocity Vector for the rotor profile with Rex value 0.823 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.23.

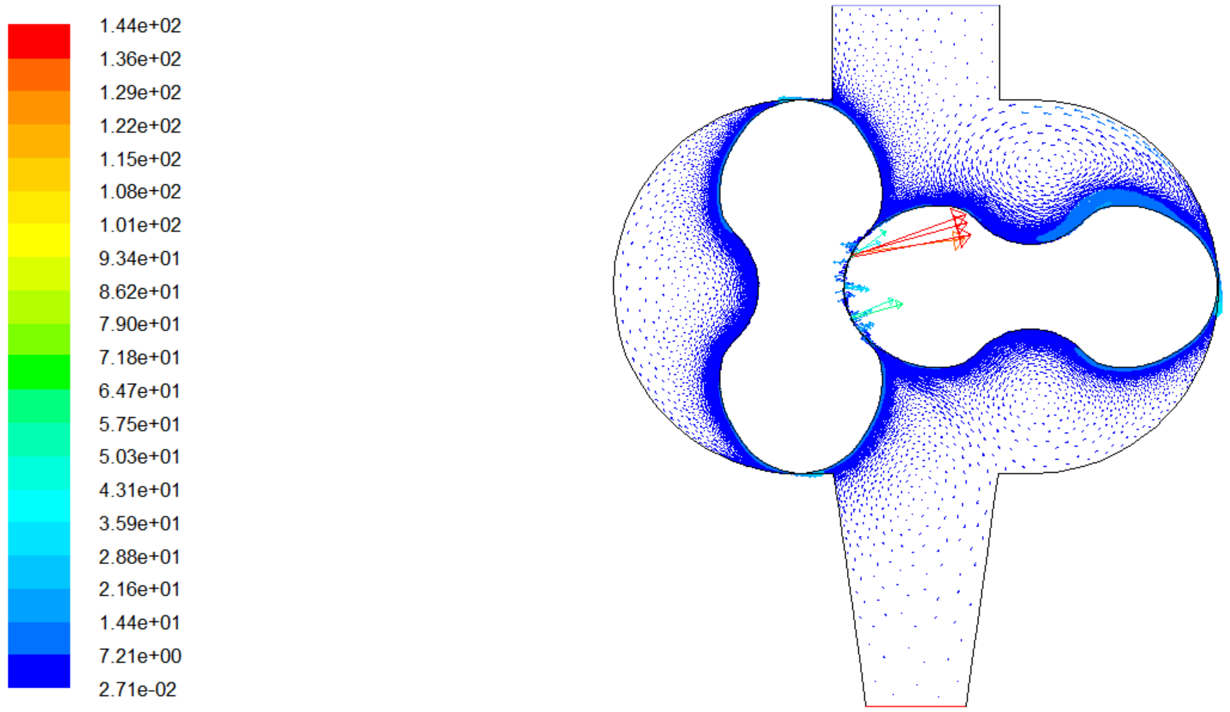

Figure 4.23: Velocity Vector at speed 300 rad/sec with Rex value 0.823 inch.

4.4.5 TEMPERATURE CONTOUR: The Temperature Contour for the rotor profile with Rex value 0.823 inch obtained through numerical simulation at speed 300 rad/sec is shown below in Figure 4.24.

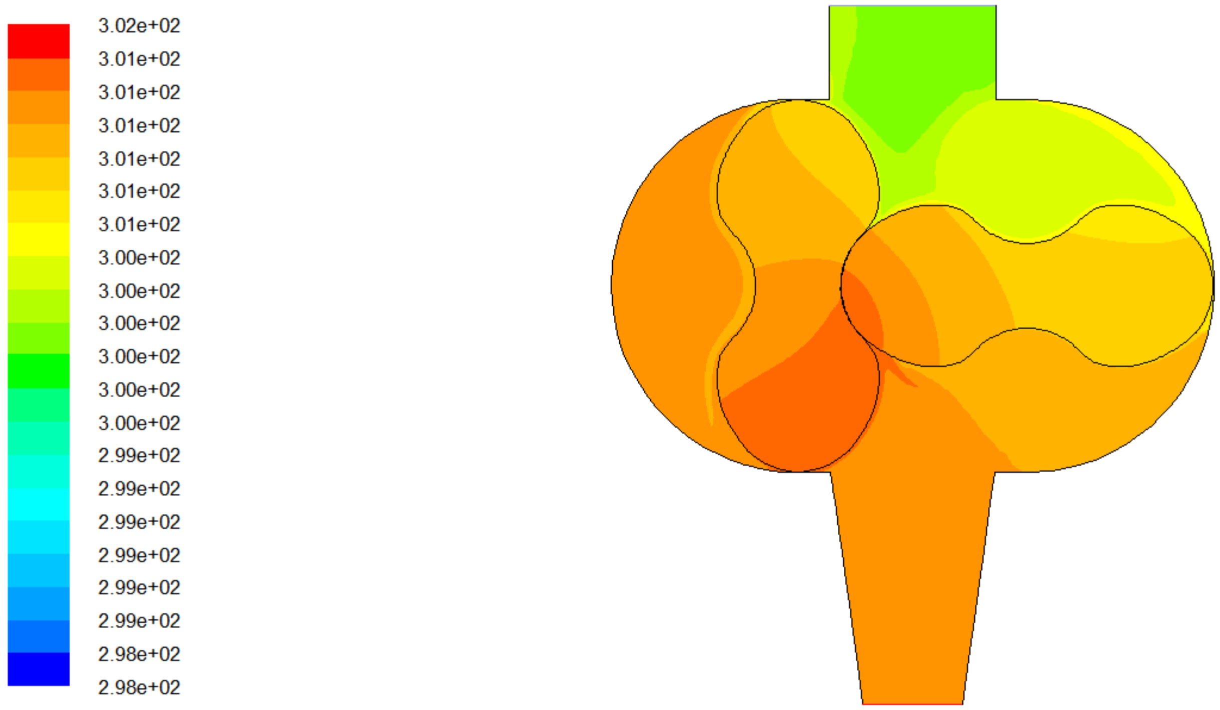

Figure 4.24: Temperature Contour at speed 300 rad/sec with Rex value 0.823 inch.

4.5 FLOW BEHAVIOR AND RESULT ANALYSIS IN 2 D MODELS

4.5.1 MASS FLOW RATE:

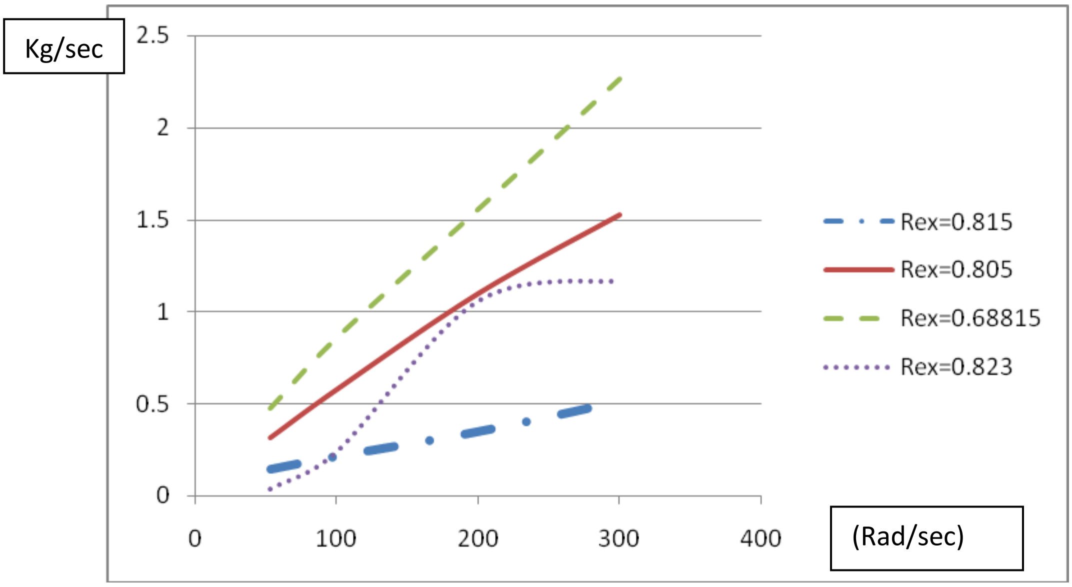

Figure 4.25: Comparision of Mass Flow Rate for 4 Rotor Profile.

In the mass flow graph a positive result is obtained that if speed ofrotation of the rotor increases, mass flow also increases. At the samme time, mass flow is also increases with the increase of clearance between the moving parts of the Roots Blower. It can be used for vacuum generation as mass flow rate in high at moderate desired vacuum level.

4.5.2 OUTLET TOTAL PRESSURE AT OUTLET (PASCAL):

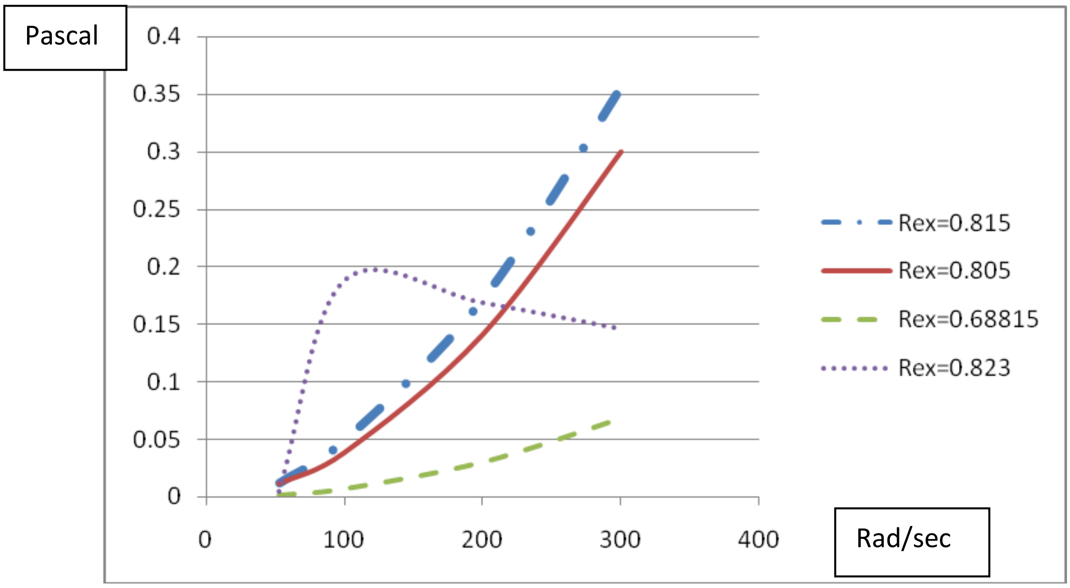

Figure 4.26: Comparision of Outlet Total Pressure for 4 Rotor Profile.

At the outlet (exhaust), the pressure is also increasing with the incresing speed of rotation. It can also be used as gas compressor. But for the higher clearance pressure rise is low as there is always some leakage. And leakage (backflow) get severe when pressur is increasing continuously at the exhaust of the system.

4.5.3 OUTLET TOTAL TEMPERATURE (K):

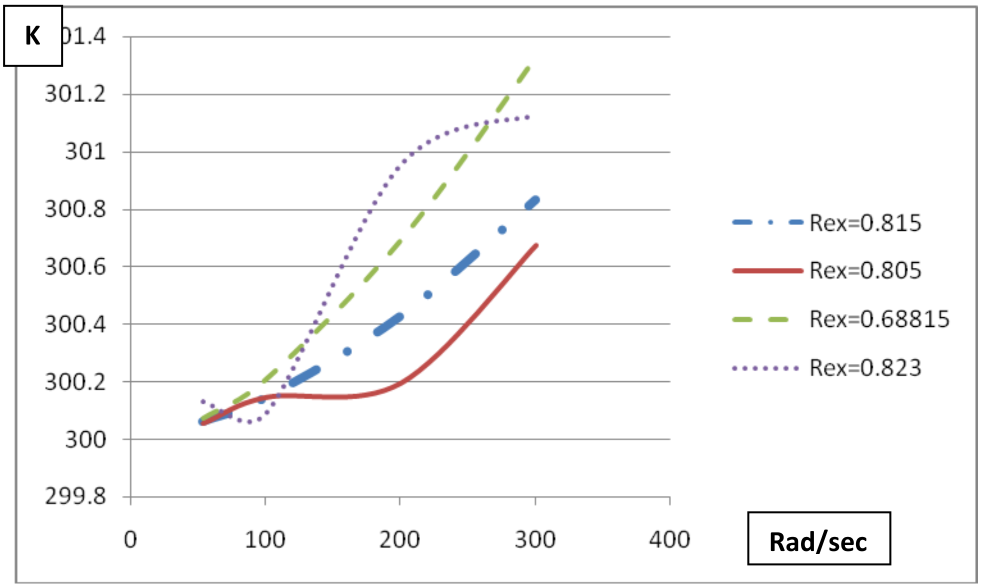

Figure 4.27: Comparision of OutletTotal Temperature for 4 Rotor Profile.

From the above graph we can see that as the rotational speed of the blower increases the temperature at the exhaust also increases. This is happen because the mechanical energy given to the rotor by rotation of the shaft is dissipating more and more into heating the Air inside the blower. From the above graph we can also see that rise in temperature decreases as clearance between Rotor- Rotor and between Rotor-Shell increases. From this we can conclude that, if there is less clearance between moving part then friction will be more hence heating of Air will be more. If clearance is more, friction will be less and so raise in temperature will be lesser. It can be used for heating the gases for some industrial and automobile purpose.

4.5.4 VELOCITY VARIATION AT OUTLET:

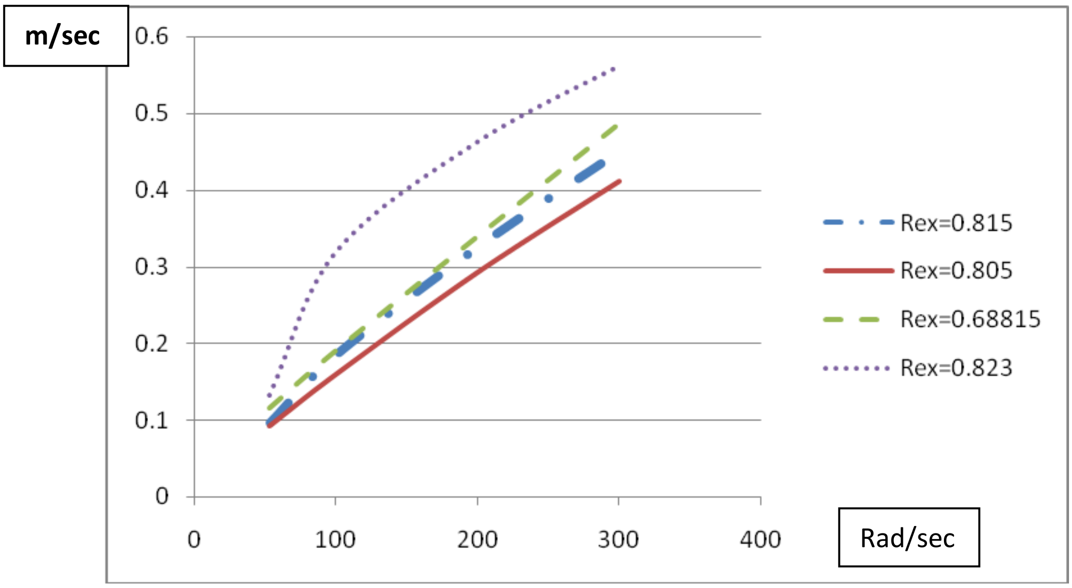

Figure 4.28: Comparision of Velocity Variation at Outlet for 4 Rotor Profile.

Velocity is also deneding on the rotor geometry profile i.e. for lower amount of crearance exhaust velocity is higher but, if clearance is more then velocity at outlet is reduced.

CHAPTER 5:

CONCLUSIONS

CONCLUSIONS

Calculations are performed on Roots blower with Computational methods using CFD package. Steady-State analysis has been done. As the rotational speed increases, the mass flow rate, temperature, pressure at the outlet side and velocity of the exiting fluid (Air) increases. But all parameter depends on the Rotor geometry, it has also been proved. Because from the result curves we have seen that they are varying in appropriate manner as the size of the Rotor get changed. For example, if clearance is increasing mass flow increasing. Pressure decreasing, temperature reducing and velocity are also reducing.

At the speed of 53 Rad/sec, 100 Rad/sec, 200 Rad/sec and 300 Rad/sec the different parameters of the flow has been studied and positive result have been found. At very high speed maximum energy is transferred in heating gas molecule hence temperature of the gas also increases at high rate. Also as the base width of the lobe is shortening, the flow through the blower is increasing but at the same time back flow is also occur due to higher clearance between the lobes.

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